ELEMENTS

OF

ASTRONOMY;

ADAPTED FOR

PRIVATE INSTRUCTION AND USE IN SCHOOLS.

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ILLUSTRATED BY FIFTY-SIX ENGRAVINGS ON WOOD.

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Among the many improvements in education which distinguish the present age, there are few more useful than the introduction of physical science as a stated part of the general instruction of youth. But as no branch of philosophy can be used for this purpose before its principles have been completely ascertained, and reduced to a systematic arrangement, it was not till a recent period that a knowledge of the laws of nature could be rendered subservient to the cultivation of the youthful mind. In our days it is pleasant to find that attempts are every where made to secure for all classes a participation in the pleasures which may be derived from studying the structure of the material universe, and, more particularly, to employ such learning as the means of mental discipline and intellectual improvement.

The usages of this country send the greater number of our youth so early into active life, and business soon becomes so engrossing, that if some provision be not made for imparting this knowledge at school, it is to be feared that many must be shut out altogether from its enjoyments, or at least partake of them in a very limited and

imperfect degree. Hence it is extremely desirable that science should be introduced as a regular part of education into all schools, and that for this purpose there should be text-books composed on its various branches to aid the pupil; it being found that the most rapid progress is made when a lesson is given out to be studied by the learner, on which he is afterwards to be examined by his teacher.

Of the various sections of Natural Philosophy, no one seems better adapted for the instruction of youth than ASTRONOMY. The phenomena it describes are interesting above all others from their grandeur as well as from their practical application to the uses of human life; while, by the exactness of its laws and the certainty of its demonstrations, it is eminently fitted to improve the mind in precision of thought and accuracy of expression. Proceeding on this view, the Author has endeavoured to prepare a little work suited both for private study and the use of schools. In executing his task, he has made it as full and accurate as possible, subdividing the matter at the same time in such a way that it can be thrown into short aphoristic sentences, which will greatly assist the pupil in forming answers to the various questions that may be put to him by his tutor.

In teaching Astronomy, one of the most difficult points is to convey to the learner a clear knowledge of the relations of the several circles, angles, and degrees on a spherical surface; and unless intimately acquainted with these, his progress will be constantly impeded by insuperable difficulties. Nor is it easy to acquire a satisfactory idea of such relations from figures drawn on a

plane surface; and hence every teacher will find much advantage in using the globe freely, and making his pupil at the outset so familiar with its several parts and the effects of its motions, that he can follow them quickly in imagination. This will, no doubt, be found a little laborious at first, but without it his notions must always be loose and confused.

The Author also strongly recommends that the learner be made acquainted at the outset with the principal stars and constellations, and the leading circles of right ascension and declination (Par. 117, page 27). Such knowledge will enable him to find out the planets, to watch their courses and those of the sun and moon through the sky, and by imparting to him an acquaintance with objects possessing so many points of attraction, will give him a more lively interest in the study. To realize these views, a considerable part of the work is devoted to an account of the starry heavens.

EDINBURGH, *April* 1842.

ERRATA.

Page 49, line 19, for "three" read "four".
20, for "four" read "three".
63, line 27, for "increase" read "increases".
121, fig. 34, for "*m*" read "M".

CONTENTS.

ELEMENTS

OF

ASTRONOMY.

INTRODUCTION.

1. ASTRONOMY is the science which treats of the heavenly bodies.

2. By the heavenly bodies, we mean the Sun, the Moon, the Earth, and the Stars.

3. Astronomy informs us of what is known regarding the FORMS of these bodies, their MAGNITUDES, DISTANCES, RELATIVE SITUATIONS, APPARENT MOTIONS, REAL MOTIONS, PHYSICAL CONSTITUTION, and ACTIONS ON EACH OTHER.

4. The term Astronomy is derived from the Greek words Αστηρ (aster), *a star*, and Νομος (nomos), *a law*. Its literal signification is, therefore, the law of the stars, or order of the stars.

5. The division of the heavenly bodies into Sun, Moon, Earth, and Stars, is a *popular* arrangement, for it classes them simply as they appear to us. It is not a *scientific* arrangement, for it is not founded on any essential differences in the nature of these bodies. The following arrangement is better.

6. The heavenly bodies are arranged in two divisions: I. THE FIXED STARS.—II. THE SOLAR SYSTEM.

7. The Fixed Stars are those stars which do not sensibly change their positions in relation to each other.

8. The Fixed Stars include all the stars usually seen in the heavens; excepting five, namely, Mercury, Venus, Mars, Jupiter, Saturn, and an occasional comet.

9. The Solar System embraces the Sun, the Planets with their Satellites, and the Comets. The Earth, Venus, Mars, and Jupiter, are *planets;* the Moon is a *satellite.*

10. The Fixed Stars, the Sun, the Planets, the Satellites, and the Comets are therefore the subjects with which it is the province of Astronomy to make us acquainted.

CHAPTER I.

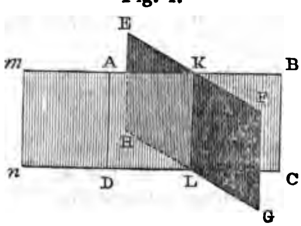
GENERAL DEFINITIONS.

11. A PLANE SUPERFICIES, PLANE SURFACE, or, as it is shortly expressed, A PLANE, is a surface of such a nature, that if a straight line be drawn between any two points in it, every point in the straight line shall touch the surface.

12. A plane, in common language, is called a *flat* surface. A wall, a well-smoothed table, a mirror, in whatever position it may be held, furnish examples of a plane surface. Its nature will be at once understood by endeavouring to apply the above definition to any curved surface, as a sphere: the straight line between two points will pass above or below the curved surface.

13. When two plane surfaces, on being produced so as to meet, would form one plane, *they are said to be in the same plane.*

Fig. 1.



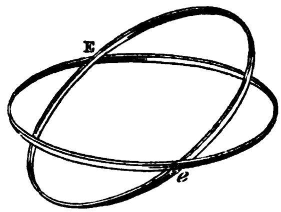
In Fig. 1, the planes m A D n, K B C L, are in the same plane, as, on being produced, they form one plane, m B C n.

14. Two tables, of the same height, and perfectly horizontal, are in the same plane.

15. When two planes, on being produced so as to meet, would cross each other, and then diverge, they are said *to be inclined to each other*, or, *to cut each other*.

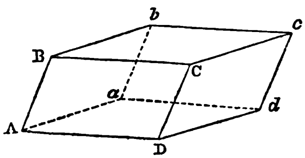
In Fig. 1, the planes EKLH, AKLD, are inclined to each other. The two planes in Fig. 2 are also inclined to each other. See also Fig. 3, in which a number of planes are shown inclined to each other.

Fig. 2.



16. Planes which never meet, when produced ever so far both ways, are said to be *parallel*. In Fig. 3, the planes B *b c* C, A *a d* D, are parallel; also the planes B *b a* A, C *c d* D.

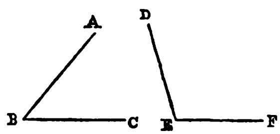
Fig. 3.



17. If two planes cut each other, the line where they meet is a straight line; as K L, Fig. 1, E *e*, Fig. 2, or any of the straight lines in Fig. 3.

18. We speak of the plane of any figure, though the interior of it be not filled up with surface, if it be one every point of which would touch a plane surface when laid upon it; as a triangle, a square, a circle, an ellipse. Such a figure is termed A PLANE FIGURE. Thus, we speak of the plane of the path of a planet, meaning the imaginary flat surface which would touch every point of the planet's course.

Fig. 4.



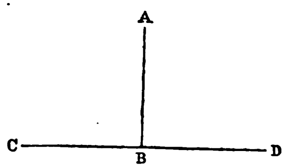
19. An ANGLE is the opening between two straight lines, which meet, but are not in the same straight line. In Fig. 4, the opening between the lines A B and C B is an angle, termed the angle B, or

the angle A B C: the letter at the point where the lines meet is placed in the middle.

20. An angle may be termed *the inclination of two lines to each other*, or, *the amount of difference of the directions in which they lie.*

21. A RIGHT ANGLE is the angle formed when one straight line stands upon another in such a direction that the angles on each side are equal to one another. These angles are termed the *adjacent angles.* In Fig. 5, A B C and A B D are right angles, for they are equal to each other.

Fig. 5.



22. The line which stands upon the other is termed a PERPENDICULAR, and is said to be *perpendicular* or *at right angles* to the other. In Fig. 5, A B is perpendicular to C D:—also, D B and C B are, each of them, perpendicular to A B.

23. A straight line is said to be perpendicular to a plane, when it is perpendicular to every straight line drawn on that plane which it meets.

24. An OBTUSE ANGLE is one which is greater, or has a wider opening than a right angle. In Fig. 4, D E F is an obtuse angle.

25. An ACUTE ANGLE is one which is less, or has a narrower opening than a right angle. In Fig. 4, A B C is an acute angle.

26. The method of comparing angles exactly, with respect to their magnitude, is described in Par. 46, page 14.

27. The INCLINATION OF A STRAIGHT LINE TO A PLANE is the acute angle contained by that line and another straight line, drawn from the point where the first line touches the plane, to the point in which a perpendicular to the plane, from any point in the first line, meets the plane.

28. The INCLINATION OF A PLANE TO A PLANE is the acute angle contained by two straight lines, one in each

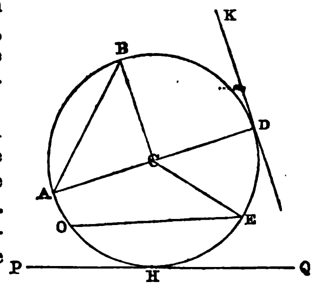
plane, drawn from any point in the line in which the planes cut each other, at right angles to that line.

29. Two straight lines which are in the same plane, and do not meet, however far they are produced both ways, are said to be PARALLEL to each other, or PARALLEL LINES.

30. Parallel lines may also be characterized as being at the same distance from each other; that is, the perpendicular drawn from any point in either line upon the other, is always of the same length.

31. A CIRCLE is a plane figure, bounded by one line, every point in which is equally distant from a certain point within the figure. The *bounding line* is called the *circumference;* the point *within,* the *centre.* In Fig. 6, C is the centre, and the curved line A B D E H O, the circumference.

Fig. 6.



32. The RADIUS OF A CIRCLE is a straight line drawn from the centre to the circumference. In Fig. 6, C A is a radius; C B and C D are also radii.

33. It follows from the above definition of a circle, that all radii of the same circle are equal in length.

34. The DIAMETER OF A CIRCLE is a straight line drawn through the centre, and terminated both ways by the circumference. In Fig. 6, A D is a diameter.

35. The diameter is double the radius; and it divides the circle into two equal parts.

36. An ARC of a circle is any portion of the circumference. In Fig. 6, D E, E H, H O, B E, E O, are arcs of the circle A B H O.

37. A CHORD of a circle is the straight line joining the two extremities of an arc. In Fig. 6, the straight lines O E, A B, are chords.

38. A SEGMENT of a circle is the part of its area cut off by any chord. In Fig. 6, O A B D E O is a segment.

39. A SEMICIRCLE is the segment cut off by the diameter, or half the area of the circle. In Fig. 6, A B D A and A H D A are semicircles.

40. A QUADRANT is the half of a semicircle. In Fig. 6, A B C A and D B C D are quadrants.

41. The terms *semicircle* and *quadrant* are sometimes applied to the portions of the circumference which bound them, as well as to the area enclosed. In this case, the semicircle is *one-half*, the quadrant *one-fourth* of the circumference.

42. A TANGENT to a circle is a straight line which touches the circle, and, on being produced, does not cut it. In Fig. 6, D K and P H Q are tangents.

43. A tangent is always at right angles to the diameter drawn through the point where it touches the circle. In Fig. 6, the angle K D A is a right angle.

44. The magnitude of an arc of a circle is described by stating what proportion of the whole circumference it forms. For this purpose, the circumference of a circle, whatever the magnitude of the circle may be, is supposed to be divided into 360 equal parts, called *degrees*, and marked °. To express still smaller parts, each degree is divided into 60 equal parts, called *minutes*, and marked ′; and each minute is subdivided into 60 equal parts, termed *seconds*, and marked ″. Thus, an arc of thirty-nine degrees, forty minutes, and thirty-one seconds, is shortly expressed, $39° \, 40' \, 31''$.

45. A semicircle is an arc of 180 degrees; a quadrant an arc of 90 degrees.

46. AN ANGLE IS MEASURED by making its sides radii of a circle, the angular point being the centre, and taking the length of the arc on which it stands, in degrees, minutes, and seconds. The arc on which the angle stands is the portion of the circumference between the extremities of its sides or radii. In Fig. 6, the angles A C E and D C E are measured by the number of degrees in the respective arcs A H E and D E, on which they stand,—the

angle A C E by the arc A H E, the angle D C E by the arc D E. We thus speak of an angle, as of so many degrees and minutes in magnitude. The angle BCD, whose arc BD is a quadrant or fourth-part of the circumference, is therefore an angle of 90 degrees. The angle D C E must be considerably less, about 60 degrees or 60°—the angle A C E, about 120°.

47. An angle of 90° is a right angle: an acute angle is less than 90°; an obtuse angle greater than 90°.

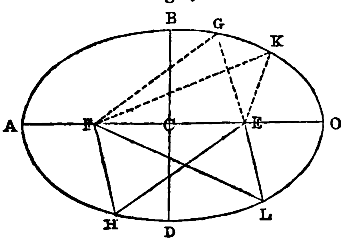
48. The arc on which an angle stands is said to *subtend* that angle. In the case of a triangle, the side opposite to an angle is also said to subtend that angle.

49. The length of the radii, or magnitude of the circle, makes no difference in the size of the angle, for the arc on which the same angle stands will always bear the same proportion to the whole circumference, however different that circumference may be, or whatever the length of the radius.

50. An ellipse is a plane figure, bounded by one line, which is of such a nature that the sum of two straight lines drawn from two points within to any point in the bounding line is always the same. These two points are termed the foci of the ellipse.

Fig. 7 represents an ellipse. F and E are its foci; and if G, K, and L, be any points in its circumference, then G F and G E together, will be of the same length as K F and K E together, or as L F and L E together.

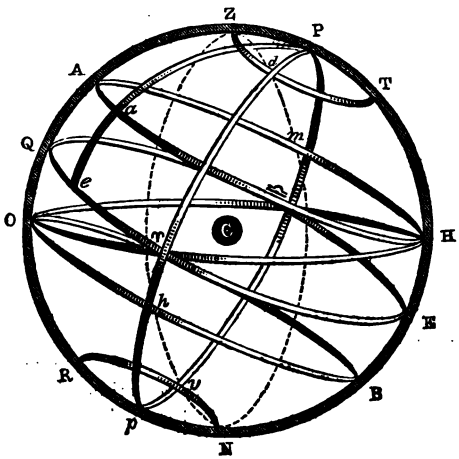
Fig. 7.



51. The major axis of an ellipse is the straight line drawn through the two foci, and terminated both ways by the circumference. The middle point of this line is the centre of the ellipse. The minor axis of an ellipse is the straight line drawn through the centre at right

angles to the major axis. In Fig. 7, A O is the major axis, C the centre, and B D the minor axis.

Fig. 8.



52. A SPHERE, commonly called a globe, is a round body having every point on its surface equally distant from a point within, termed the *centre*.

53. A DIAMETER of a sphere is a straight line passing through the centre of the sphere, and terminated both ways by its surface. In Fig. 8, straight lines drawn from P to *p*, and from Z to N, are diameters.

54. A GREAT CIRCLE of a sphere is a circle drawn upon its surface, whose plane passes through the centre of the sphere. In Fig. 8, P♈*p v*, Z *h v* N *m*, E♈*e* Q, and H ♎ O ♈, are great circles.

55. All great circles of a sphere are equal to each other.

56. A SMALL CIRCLE of a sphere is a circle drawn upon its surface, whose plane does not cut the centre of

the sphere. In Fig. 8, Z *d* T, A *a* H, N *v* R, are small circles.

57. Two great circles of a sphere crossing each other, divide each other into two equal parts or semicircles. In Fig. 8, each of the great circles P ♈ *p*, Q *e* ♈ E, divide each other into two equal parts or semicircles; the former into ♈ P ♎ and ♎ *p* ♈, the latter into ♎ Q ♈ and ♈ E ♎.

58. Distances on a sphere, and the breadth or length of figures on its surface, are expressed in degrees of some of the circles drawn on its surface.

59. When a sphere revolves, like a top spinning, turning on itself without moving out of its situation, this is termed *rotation on its axis*. The AXIS is the diameter about which it rotates, which does not shift its position, while the other parts describe circles around it.

60. The two extremities of the axis are termed POLES of the sphere.

61. The extremities of a diameter at right angles to the plane of a great circle are sometimes termed the POLES of that great circle. In Fig. 8, P *p* are the poles of the great circle E ♈ *e* Q; Z N, the poles of the great circle H ♈ O ♎.

62. The poles of a great circle are each of them 90° distant from that circle. That is, if a great circle be drawn through the poles of any great circle, cutting the latter, the part of the former between each pole and the second great circle will be 90°, or 1-4th of the whole circumference. In Fig. 8, the arcs P *a e*, P *d* ♈, between the great circle E ♈ Q and its pole P, are arcs of 90° each.

63. A SPHEROID is a figure like a sphere, but having its surface flattened at the two extremities of one of its diameters, like an orange. That diameter is the shortest, and the diameter at right angles to that one is the longest diameter, of the spheroid.

64. APPARENT MOTION is the apparent change of a body's position, arising, not from a real motion of the

body, but from an actual change in the position of the observer. It is sometimes termed *relative motion*.

65. Real motion is when the body which appears to move actually does change its position. This is sometimes termed *absolute motion*.

66. A person moving along a road in a carriage has real or absolute motion; while the change of position he observes in the trees, houses, &c., is only an apparent or relative motion of these objects.

CHAPTER II.

THE FIXED STARS.

67. The fixed stars are those stars which preserve without material change the same relative position to each other.

68. That is, any fixed star will be found at all times to be nearly at the same distance from any other fixed star, and to form the same angle with any other two fixed stars. Therefore they always preserve the same arrangement or figure. They present the same general appearance to us as to the ancients, thousands of years since.

69. The "fixed stars" are not absolutely fixed. Many of them do change their positions in relation to each other. But this change, called their *proper motion*, is very slight; so much so, that it must go on for thousands of years before it amounts to a change in position sensible to the naked eye.

70. Arcturus moves north about 2″ yearly, that is, 1′ in 30 years, or 1° in 1800 years. He thus requires nearly 2000 years to move north so much as 1-360th part of a great circle of the heavens. The two stars 61 of the Swan shift their position about 5″·3 annually.

71. The fixed stars have a slight *apparent* motion, arising from the *precession of the equinoxes;* which see.

72. These two motions conjoined occasion what is termed the *annual variation* in the position of the fixed stars.—See the Nautical Almanac.

73. The fixed stars are so named in contradistinction to the planetary or cometary stars, which are seen to be in continual motion from one part of the heavens to another.

74. All the stars usually seen in the heavens by the naked eye are fixed stars, excepting five, and an occasional comet.—See Par. 8. They may be distinguished from the planets and comets by their property of *twinkling*, that is, alternately expanding and contracting their rays. The planets shine with a steady equal light.

75. Very little is known regarding the fixed stars. We can judge of their *relative brightness*, we can ascertain the direction and velocity of their *apparent daily motion round the earth*, and any other motions they exhibit, and we can determine that they are at not less than a certain distance from us. But we do not know their actual magnitude, nor their actual distance from the earth.

76. We have no knowledge of THEIR SIZE, for, even when viewed through the telescope, they present no disc or surface, whose breadth can be measured. Even by the aid of this instrument, they appear, as to the naked eye, brilliant shining points, more bright and luminous.

77. The different magnitudes which the fixed stars present to us, may arise from their different distances, different degrees of brightness, or from actual differences in magnitude: being ignorant of the two former, we have no data for judging of the latter.

78. From the great brilliancy of Sirius, the dog-star, it has been calculated that it cannot be less than twice, and may probably be fourteen times as bright as the sun.

79. We have no knowledge of the ACTUAL DISTANCE of any of the fixed stars; for no one has yet been found which gives a sensible parallax* with the diameter of

* See Parallax.

the earth's orbit, a distance of 190 millions of miles. It can be shown from this, that the distance of the nearest of those whose parallax has been attempted, cannot be less than 19,200,000,000,000, that is, upwards of 19 millions of millions of miles.

80. It is most probable that many of the fixed stars are at distances infinitely greater than this, being rendered visible to us from their immense magnitude and brightness. The above distance is so great, that light, which travels at the rate of 192,000 miles in a second, must require at least three years to come to the earth from the nearest fixed star; and the rays which reach us, therefore, have proceeded from the star at least three years previously.

81. The fixed stars are supposed to be suns, having planets revolving round them, which they preserve in their orbits, supply with heat and light, and thus render fit to be places of abode for living beings.

82. It is considered that they are independent systems, not subservient to our universe, much less to our earth; because they shine from their own light, because from their great distance their influence on the solar system must be very slight, and because it is improbable that bodies of the magnitude which their distance shows the fixed stars to possess, are subsidiary to our comparatively small system. That the stars shine by their own inherent light, not by reflecting the sun's rays, is shown by their enormous distance from that luminary.

83. The fixed stars are arranged according to four different principles.

1. According to their brightness.
2. In constellations.
3. According to their situation in the heavens.
4. According to their kind, so far as that can be discovered.

1. *Division of the Stars according to their Brightness.*

84. The fixed stars are divided according to their brightness into classes, termed *magnitudes*. The brightest are said to be of the *first magnitude*, the next in point

of brightness, of the *second magnitude*, and so on. With powerful telescopes, the range is continued down to the 16th magnitude.

85. There are about 20 stars reckoned of the first magnitude. Of these 11 are visible in Great Britain. SIRIUS, the dog-star, is the brightest of the stars of the first magnitude.

86. There are about 60 of the second magnitude, 200 of the third magnitude, 1000 of the fourth magnitude, and nearly 20,000, including the seventh magnitude. Altogether, there are myriads,—infinitely more than can be reckoned.

87. Seldom above 2000 are visible at a time to the naked eye. Those of the 5th and brighter magnitudes may, on a clear night, be discerned without the aid of a telescope.

88. The milky way is composed of innumerable stars, whose average brightness is about the 11th magnitude, and whose joint light is therefore separated only by very powerful telescopes.

89. Every increase in the powers of the telescope brings new stars into view, and as their distances are so great, it is possible that there may be myriads of stars so remote from our system that their light has never reached the earth, though they may have been created at the same period as our system; while others, whose light still reaches us, may have been long since extinguished. There is no reason to suppose that the boundaries of the sidereal system (if it have a limit) are within reach of even our most powerful telescopes. The most remote of the stars which the best telescopes bring into view, may owe their apparent minuteness not to inferior magnitude, but to immense distance; and, perhaps, an observer at the furthest of these would find the same appearance as we do, star beyond star in countless myriads and at inconceivable distances, of which it baffles the mind to form any adequate conception.

2. *Arrangement of the Fixed Stars in Constellations.*

90. A CONSTELLATION, in astronomical language, signifies a collection of adjoining stars, separated from the

others by an imaginary line, and included under one name, expressive of some figure which the leading stars in the constellation are supposed to resemble.

91. The stars in each constellation are named according to the letters of the Greek alphabet,—the brightest being termed α (alpha), the first letter; the next brightest β (beta), the second letter, and so on. When there are more stars in the constellation than there are letters in the Greek alphabet, the remainder are indicated by numbers. The leading stars in the constellations have usually some name applied to each, as Sirius, Arcturus, Aldebaran, Vega, &c.

The following figure will explain what is meant by a constellation.—See next page.

92. At the top is observed a cluster of stars disposed within the figure of a small bear, which is surrounded by a line separating it from the adjoining stars. The stars within that line form a *constellation*, termed URSA MINOR, or the *Little Bear*.

93. In the same figure are seen parts of other constellations—the GREAT BEAR (Ursa Major), the DRAGON (Draco), the CAMELOPARD, the hand of BOOTES, and, near the Little Bear, the feet of CEPHEUS.

94. The constellations are arranged in three divisions, the NORTHERN, SOUTHERN, and ZODIACAL constellations.

95. The zodiacal constellations form a belt round the heavens, termed the ZODIAC.

96. The northern constellations are those on the same side of the zodiac as the north pole-star, lying around that star.—The southern constellations are those further south than the constellations of the zodiac.

97. The north pole-star is the brightest star in the constellation termed the Little Bear, at the tip of its tail. It is marked P S in Fig. 9. The north pole-star is easily found out, by means of the well-known seven bright stars commonly called the *Bear*, the *Plough*, or *Charles' Wain*. These stars are seen in Fig. 9, about the lower half of the right hand side. If, when these stars are in any position, a line be drawn through the two (β and α)

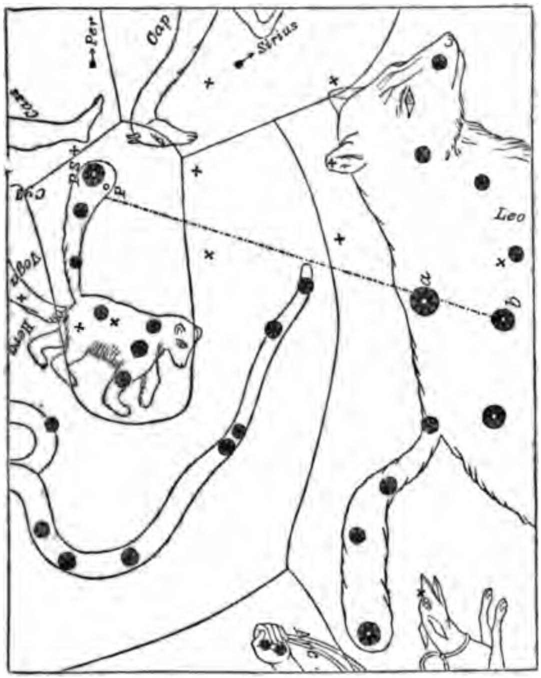


Fig. 9.

furthest from the tail, and produced in a direction *from* the limbs of the animal, that line will pass close to the north pole-star, at about four times the distance from the Bear of these stars from each other. These two stars are termed "the pointers."

98. In the above figure, this line is represented, drawn through the stars β and α of the Bear, and passing close to P S, the north pole-star.

99. The north pole-star is a star of the second magnitude. It is not precisely on the north pole of the heavens, but a little distance (about 1° 32′) from the

true north pole. The north pole is the small circle, like the sign for a degree, marked P in Fig. 9.

100. The division of the stars into constellations, as at present arranged and named, is very ancient.

The position and method of finding several of the leading stars and constellations will be described in Par. 119, &c. under the next subdivision.

3. *Arrangement of the Fixed Stars according to their Position in the Heavens.*

101. It is necessary, for astronomical purposes, to be able to define the exact position of the stars in the heavens. This is done by taking certain fixed points or lines, and marking the distance of each star from these points or lines.

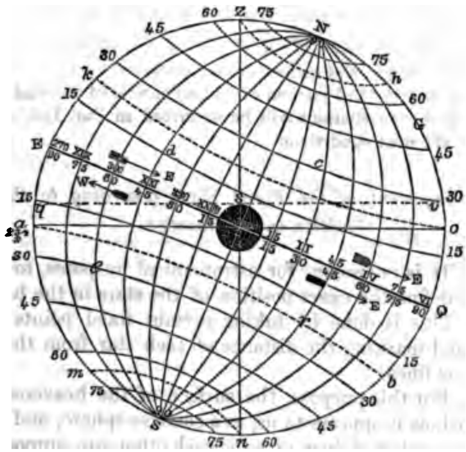
102. For this purpose, the surface of the heavens is regarded, as it appears to us, as a concave sphere, and an infinite number of lines, crossing each other, are supposed to be drawn upon it. These lines are divided into degrees, numbered from certain fixed points; and by observing the position of a star on these lines, where two of them cross each other, its situation can be determined with great precision. This is illustrated by the following figure.

103. Two points are taken in the sphere of the heavens, one close to the north pole-star, the other at the opposite extremity of the diameter passing through the first point. These are represented by N and S in Fig. 10. The first, N, is termed the NORTHERN POLE OF THE HEAVENS; the second, S, the SOUTHERN POLE OF THE HEAVENS. These are the primary fixed points.

104. An infinite series of great circles is supposed to be drawn on the sphere, all passing through the two poles. These are represented in Fig. 10 by N E S, N *e* S, N *d* S, N *c* S, N *r* S, N Q S; only one half of each being seen in the figure. These are termed HOUR-CIRCLES.

105. A great circle, at right angles to these hour-circles, and at equal distances from each pole, is termed

Fig. 10.



THE EQUINOCTIAL. It is 90° from each pole, and is represented by the line E Q in Fig. 10.

106. A series of small circles are supposed to be drawn north and south of the equinoctial, and parallel to it, lying between it and each pole. These are represented in Fig. 10 by Z *h*, *k o*, &c., north of the equinoctial, and *q* 15, *a b*, *m n*, &c., south of the equinoctial. These circles are termed PARALLELS OF DECLINATION.

107. All these circles are supposed to be divided into degrees, minutes, and seconds, as described in Par. 44.

108. In any hour-circle there will be an arc of 90 degrees between the point where it crosses the equinoctial and either pole, and that arc will be crossed by every parallel on the same side of the equinoctial. Accordingly, each *parallel* is named by its distance north or south from the equinoctial, measured by the number of degrees along an hour-circle which it is distant from the equinoctial. Thus, from E by Z to N is 90° of the hour-circle N E S Q. The first parallel shown north of E Q crosses N E S Q at 15° from E Q; that parallel (15 *d* 15) is therefore 15°

north: its distance north of E Q is termed its NORTH DECLINATION; and every point in that parallel, as *d*, being at the same distance from E Q, has the same DECLINATION.

109. The point *c* is in *north declination* 30°, the point *e* in *south declination* 30°. See also Fig. 8, page 16, in which P *p* are the poles; E ♈ Q, the equinoctial; Z *d* T, A *a* H, O *h* B, parallels; P *a e*, P ♈ *p*, hour-circles. In that figure, the arc *e a* is the north declination of *a*; the arc ♈ *d*, the north declination of *d*; E B, the south declination of B.

110. The equinoctial circle is in like manner divided into 360 degrees, &c., which are numbered from the point where it is crossed by the hour-circle which passes through the first point of the sign ARIES. This point is called the EQUINOX, and is represented at 360, in the middle of the line E Q in Fig. 10. It is usually marked by the sign ♈.—See Fig. 8. Every hour-circle crosses the equinoctial, and each is named according to the degree, minute, &c., where it cuts the equinoctial. The distance of an hour-circle from the equinox is termed its RIGHT ASCENSION. Thus, the hour-circle N *r* S, crossing the equinoctial at 45° from the equinox, any point in that half (N *r* S) is said to be in *right ascension* 45°.

111. Thus, by knowing the parallel of declination and hour-circle in which a star is situated, we know its precise position, as every parallel crosses every hour-circle.

112. In Fig. 8, page 16, if P and *p* represent the poles of the heavens, and E ♈ *e* Q the *equinoctial*, the number of degrees from *e* to *a* will be the declination north of the point *a*, and its right ascension will be the number of degrees from ♈ round by E, ♎, and Q, to *e*, ♈ being the equinox, or point in the equinoctial from which the degrees are reckoned. In Fig. 10, the point *c* is in right ascension 30°, *north declination* 30°: the point *d* in *right ascension* 315°, north declination 15°; and so on.

113. R. A. is the contraction used for right ascension; D. N. declination north; D. S. declination south.

114. The distances from the equinox are sometimes reckoned in *hours*, each hour consisting of 15 degrees,

and being divided into 60 minutes. In Fig. 10, *above the line* E Q, the degrees are marked alternately in hours and degrees: thus, commencing at the equinox, we have first 15°, next II hours (30°), then 45°, then IV hours (60°), 75°, VI hours (90°), &c.

115. The degrees of right ascension are reckoned *eastward* from the equinox, all the way round from 0° to 360°: that is, in the direction FROM THE HEAD TOWARDS THE TAIL OF THE GREAT BEAR, *when that constellation is between the pole-star and the horizon.*

116. The places of the sun and planets are expressed in the almanacs by stating their right ascension and declination; as in White's Ephemeris, the Nautical Almanac, or Oliver and Boyd's New Edinburgh Almanac. Thus, in the latter, for 1842, the situation of the planet Venus, on November 1st, is Dec. S. 27° 46′ (declination south twenty-seven degrees forty-six minutes), and R. A. $17^{h.}$ $28^{m.}$ (right ascension seventeen hours twenty-eight minutes).

117. The student is here strongly recommended to make himself acquainted with the right ascension and declination of several leading stars, so that he knows thoroughly and can trace out for himself, on viewing the heavens, the position of the leading hour-circles and parallels. A very little attention at first will easily enable him to do this; and when he has thus got a knowledge of some of the leading lines by which the positions of the stars are defined, and an idea of the extent of the heavens indicated by a given number of degrees, he will find it very easy to discover the following stars and constellations; as well as any other star or planet whose R. A. and Dec. he knows.

118. The following are several of the leading stars and constellations, with instructions by which they may be easily found out by the learner.

NORTHERN CONSTELLATIONS.

119. The GREAT BEAR (*Ursa Major*) is well known. Its seven leading stars are in the body and tail of the figure. The greater part of this constellation is shown in Fig. 9. Its brightest star, one of the pointers, marked *a* in Fig. 9, and termed DUBHE, is in R. A. $10^{h.}$ $53^{m.}$, or about 163°;

and D. N. 62° 37′. The star at the tip of the tail, called BENETNASCH, is in R. A. $13^{h.}$ $41^{m.}$, or about 205°; D. N. 50° 7′.

120. Upon the other side of the Little Bear, but nearer to it, is an irregular cluster, which have been thrown into a male figure called CEPHEUS. The feet of Cepheus are seen in Fig. 9.

121. A line drawn from about the middle of the tail of the Great Bear through the pole-star, and produced nearly as far on the other side of that star, will terminate in the constellation CASSIOPEIA, or Lady in her Chair. The principal stars in this constellation are five in number, and arranged somewhat like the letter W, but straggling, and with one angle shorter than the other. Cassiopeia is one of the constellations in the milky way.

122. A straight line from the pole-star, perpendicular to the line joining the pointers and pole-star, and on the same side of that line as the head of the Great Bear, passes through a very bright star, CAPELLA; about twice as far from the pole-star as the pointers. This star is in R. A. $5^{h.}$ $4^{m.}$, or about 76°; D. N. 45° 49′. This is the brightest and most northern of the leading stars in the constellation AURIGA, or the Charioteer. The principal stars in this constellation, along with one of Taurus, form an elongated five-sided figure, stretching from north to south, and very well marked. Capella does not set in Great Britain.

123. Between Capella and Cassiopeia, but further south, is the constellation PERSEUS. Three of its leading stars form a gentle curve.

124. A straight line from the pole-star, in the direction nearly opposite to the line cutting Capella, leads to another very bright star, VEGA, the principal star in the constellation LYRA. Vega is in R. A. $18^{h.}$ $31^{m.}$, or about 277°; and D. N. 38° 38′. This star does not set in Great Britain, just skirting the horizon.

125. East of Vega, in R. A. from $20^{h.}$ to $21^{h.}$, and D. N. about 33° to 47°, are seen four bright stars, three nearly in a line, and one above the middle of the three: these are the principal stars in the constellation CYGNUS, or *Swan*, which lies in the milky way.

126. A straight line from the pole-star, passing near the star in the tip of the tail of the Great Bear, and twice the distance of the tail from the pole-star, cuts ARCTURUS, a

very bright star, of a distinct reddish colour, the principal star in the constellation BOOTES, or the *Huntsman.* Arcturus is in R. A. $14^{h.}$ $8^{m.}$ or about 212°; and D. N. 20° 1′.

127. A straight line south from Cassiopeia, and nearly at right angles to the line joining Cassiopeia and the Swan, will pass near a large square of four stars; the furthest north and brightest of which is ALPHORAT, the principal star in the constellation ANDROMEDA; while the other three of the square are part of the constellation PEGASUS. The star Alphorat is in R. A. $0^{h.}$ $0^{m.}$ $4^{s.}$, about 0°, that is, on the hour-circle crossing the equinox; D. N. 28° 12′. It is on the eye of Andromeda, which constellation stretches eastward across the heavens towards Perseus, from Alphorat.

128. The constellation Cassiopeia has nearly the same R. A. as Alphorat; or rather between $0^{h.}$ and $1^{h.}$ eastward.

129. Between Arcturus and Vega, but considerably nearer Arcturus, is a half circle of stars, termed CORONA BOREALIS.

130. South-east of CORONA lies the great constellation HERCULES.

ZODIACAL CONSTELLATIONS.

131. These are twelve in number, and encircle the heavens like a belt. They are named ARIES, the Ram; TAURUS, the Bull; GEMINI, the Twins; CANCER, the Crab; LEO, the Lion; VIRGO, the Virgin; LIBRA, the Balance; SCORPIO, the Scorpion; SAGITTARIUS, the Archer; CAPRICORNUS, the Goat; AQUARIUS, the Waterman; PISCES, the Fishes. The constellations of the zodiac do not rise high above, nor sink far below the horizon in Great Britain.

132. The sun, moon, and principal planets, are always found in some of the constellations of the zodiac.

133. The brightest star in ARIES is in R. A. $1^{h.}$ $58^{m.}$, about 29°; D. N. 22° 41′.

134. ALDEBARAN, the brightest star in TAURUS, is in R. A. $4^{h.}$ $26^{m.}$, about 66°; and D. N. 16° 10′. The PLEIADES, or seven stars of Taurus, are in R. A. about 54° 30′, and D. N. 23° 30′.

135. CASTOR and POLLUX, the brightest stars in Gemini, are very near each other; Castor, in R. A. $7^{h.}$ $24^{m.}$,

or about 111°; and D. N. 32° 14′: Pollux, in R. A. 7h. 35m., or about 114°; and D. N. 28° 24′.

136. There are no very prominent stars in the constellation CANCER.

137. REGULUS, the principal star in LEO, is in R. A. 9h. 59m. about 150°; D. N. 12° 45′. The leading stars in this constellation form a figure like a sickle, of which Regulus is in the handle. This great constellation is nearly due south of the Great Bear.

138. SPICA, the brightest star in VIRGO, is in R. A. 13h. 16m., or about 198°; and D. S. (declination south) 10° 19′.

139. The constellations LIBRA, SCORPIO, SAGITTARIUS, are seldom seen in Great Britain.

140. AQUARIUS is south-west of Pegasus; PISCES, south and south-east of Pegasus. There are no very bright stars in these constellations.

SOUTHERN CONSTELLATIONS.

141. The only southern constellations of interest that are frequently visible in Great Britain are, ORION, CANIS MINOR, and CANIS MAJOR: these constellations lie due south of CAPELLA and GEMINI, and are very prominent in the heavens during our winter.

142. ORION is a large prominent figure, a little east of due south from Capella. It is in the form of a four-sided figure, considerably elongated from north to south. In the middle are three stars, lying in a south-east and north-west direction, usually termed ORION'S BELT. BETELGEUX, the brightest star in Orion, is in the north-east angle. It is of a distinct reddish colour. It is in R. A. 5h. 46m., about 87°; in D. N. 7° 22′.

143. SIRIUS, in the constellation CANIS MAJOR, the greater dog, and the brightest of the fixed stars, is south-east from Orion, in R. A. 6h. 38m., about 100°, and D. S. 16° 30′. The Pleiades, Aldebaran, Orion's Belt, and Sirius, are nearly in one straight line.

144. PROCYON, a star of the first magnitude, in the constellation CANIS MINOR, or lesser dog, is nearly due south from the Twins, and due east of Betelgeux. Its R. A. is 7h. 30m., about 112°; its D. N. 5° 37′.

145. The MILKY WAY, another prominent object in the heavens, lies between PROCYON and SIRIUS, passes north-

west between GEMINI and ORION, nearer Orion, through AURIGA, south-west of CAPELLA; then continues in the same direction successively through PERSEUS, CASSIOPEIA, and CYGNUS, and south-west, splitting into two divisions south from Cygnus.*

4. *Arrangement of the Stars according to other Differences than their apparent Brightness or Situation.*

146. Considered with respect to other differences than their situation or brightness, the fixed stars may be divided into six kinds:—1. Ordinary fixed stars; 2. Temporary stars; 3. Variable stars; 4. Double stars; 5. Nebulæ; 6. Clusters of stars.

I. ORDINARY FIXED STARS.

147. These are the stars which, either to the eye or in the telescope, do not present any peculiar phenomenon, such as variation in lustre, motion, nebulous appearance, or are not aggregated with any other stars in a distinctly separate cluster. This is the case with a large proportion of the fixed stars.

II. TEMPORARY STARS.

148. These are stars which have appeared for a limited time, and then disappeared. Many stars, given in old catalogues, are not to be seen now; and on several occasions, in various parts of the heavens, new stars have suddenly come into view, and disappeared at longer or shorter intervals, shining with various degrees of brilliancy during their short career.

149. It is said that it was the sudden appearance of a new and bright star in the heavens, about 125 B. C., which led the illustrious ancient astronomer HIPPARCHUS to the idea of making a catalogue of the stars, which he did. Some of these, which have appeared at different periods, are conjectured to be periodical in their visitations, especially the stars of 945, 1264, and 1572, which appeared in the same region

* See Six Maps of the Stars, published by the Society for the Diffusion of Useful Knowledge.

of the heavens, and have been thought to be *the same star* with a period of about 300 years.

III. VARIABLE STARS.

150. The variable stars present the singular phenomenon of a change in their brightness; they undergo a regular alternate increase and diminution in their lustre; and several altogether disappear for a time. They are sometimes termed *periodical*.

151. The second star, β, in the constellation PERSEUS, is a variable star, the phenomena of which are visible to the naked eye. It is just on the margin of the milky way, on the side of it farthest from the north pole-star, and about the same distance from that star as Vega. It is in R. A. 45°, D. N. 40°. It may be found by drawing a line from the pole-star in the direction of the letters *Per*, in Fig. 9, page 23.

"This star, named ALGOL, is usually visible as a star of the second magnitude, and such it continues for the space of $2^{d.}\ 14^{h.}$, when it suddenly begins to diminish in splendour, and in about 3½ hours is reduced to the fourth magnitude. It then begins again to increase, and in 3½ hours more is restored to its usual brightness, going through all its changes in $2^{d.}\ 20^{h.}\ 48^{m.}$"—*Herschel.*

152. This singular and regular change in the brightness of the variable stars, is attributed to the revolution of some body round them, sufficiently large to cut off a portion of their light when interposed between the earth and the star, though not of sufficient magnitude to eclipse the star altogether.

153. The following are some of the leading variable stars visible in Great Britain. β (beta) of Perseus; δ (delta) of Cepheus; β (beta) of Lyra, a little south from Vega; α (alpha) of Hercules; ο (omicron) of Cetus. These have periods varying from about 3 to 334 days, that of omicron of Cetus. The latter is one of those variable stars which disappear altogether for a time. It is called MIRA, is a star of the second magnitude when at its brightest, in R. A. about 32° or $2^{h.}\ 10^{m.}$, and D. S. between 3° and 4°. It is nearly due south of the leading stars in ARIES.

IV. BINARY STARS.

154. BINARY stars are those stars which, on examination with the aid of a powerful telescope, and observation for a considerable time, are found to consist of two stars nearly equal in apparent magnitude, and having a revolution round each other.

155. This great discovery was made by SIR WILLIAM HERSCHEL, towards the close of the last century. It was first publicly announced in papers read to the Royal Society of London in 1803.

156. About forty binary stars have been discovered, and the periods of revolution of many of them have been determined. In CASTOR, which is a binary star, the revolution is completed in 252·6 years. In a binary star in Corona Borealis the orbit is completed in 43·4 years; and therefore a complete period has in this instance been gone through since the discovery by Sir W. Herschel.

157. The following are some of the most remarkable of the binary stars: γ (gamma) of the constellation Virgo; η (eta) of Corona; η (eta) of Cassiopeia; γ (gamma) of Leo; δ (delta) of Cygnus; γ (gamma) of Andromeda.

158. The binary stars are often coloured, each being of a different hue; and they usually exhibit those tints which are called complementary, as blue and yellow—red and green.

159. The phenomena of periodical and binary stars seem to indicate that among the fixed stars there are the same general laws which prevail in our solar system; for wherever we observe motion in an orbit, there we must infer the existence of some force analogous to that of universal gravitation.

160. Stars of nearly equal magnitude, and placed close to each other, but in which no revolution has yet been detected, are termed DOUBLE STARS. Of these, there is a very great number.

V. NEBULAE.

161. Nebulae are faintly luminous stars, different from either of the preceding varieties. The leading kinds are two:—(1.) Those which are resolved by powerful telescopes into a collection of separate stars, densely crowded into one luminous mass in the centre, but becoming scattered and separate towards the borders. These are regarded as systems of suns,—as a whole world of stars, separate from other systems; the individuals of which are probably suns, at as great distances from each other as from our system.

162. (2.) Another kind of nebula, to which the term nebula is most usually applied, is that in which the star appears a thin cloudy mass, of that fleecy appearance observed in the tail of a comet. The latter nebulae, it has been imagined, may be gaseous matter in the process of formation into suns with their attendant planets; perhaps a condensation of the ethereal matter which is conjectured to be diffused through space.

VI. CLUSTERS OF STARS.

163. Where there are a number of stars gathered together, apart from the others, and forming in a manner an isolated group, they are termed a *cluster*, and are considered to belong to some system separate from the general body of the stars.

164. The MILKY WAY, the PLEIADES, COMA BERENICES, are examples of these clusters. The milky way owes its light to myriads of stars closely crowded together, of which it is found to be composed, when viewed through powerful telescopes.

165. The stars are supposed not to be scattered indiscriminately through the heavens, but to be arranged according to a definite order, of which some glimpses have been obtained. Our star, the sun, is supposed to belong to that cluster which forms the milky way, being placed near the middle of it.

CHAPTER III.

THE SOLAR SYSTEM.

166. The solar system consists of certain of the heavenly bodies which are connected with the sun, and form a system by themselves, apart from the others. They are termed "the Solar System," from "Sol," the Latin word for "the sun."

167. The SUN, PLANETS, SATELLITES, and COMETS, constitute the solar system.

168. The connexion between these bodies is this:—The planets and comets revolve round the sun in regular periods of time, receive heat and light from him, and are preserved by his action in their proper paths around him. The satellites revolve round some of the other planets, are carried with them round the sun, and also receive heat and light from that luminary.

169. The path, or course, in which any of the heavenly bodies moves, is termed its ORBIT; from the Latin, *orbita*. The orbits of the planets are ELLIPSES; the sun being in one of the foci.

170. The PLANETS are those stars which do not remain in one spot, but are found to change their positions in the heavens. They are therefore termed *planets*, from the Greek word πλανήτης, signifying a wanderer. They are so named in contradistinction to the fixed stars, which preserve their relative positions unchanged.

171. Their motion round the sun is in the same direction as that of the earth, *from west by south to east;* they also revolve on their axes, and this motion likewise is performed in the same direction—from west to east.

172. The planes of the orbits of the planets are not much inclined to that of the earth's orbit; but all are inclined to it in some degree, so that one-half of a planet's course lies north of the plane of the earth's orbit,—the other half south of it. In consequence of the

various orbits being nearly coincident in their planes, the planets usually appear in one zone or belt of the heavens, called the ZODIAC. Excepting three of the asteroids, the planets are always seen among the stars of the constellations of the zodiac.

173. The planets appear to be worlds like our earth. They are opaque, and dark in themselves, but shine by reflecting the light which they receive from the sun. It is most probable that, like the earth, they are the abodes of animate beings.

174. The planets at present known are *eleven* in number, viz. MERCURY, VENUS, the EARTH, MARS, VESTA, JUNO, CERES, PALLAS, JUPITER, SATURN, and URANUS. These are sometimes termed *primary planets.* Of these, four very small planets, recently discovered, and all very near to each other, are termed ASTEROIDS,—namely, Vesta, Juno, Ceres, Pallas.

175. The SATELLITES are those smaller planets which revolve round several of the primary planets as a centre—such as our moon. They are sometimes termed *moons* or *secondary planets.* The term "satellite" is taken from the Latin word *satelles*, a guard or attendant.

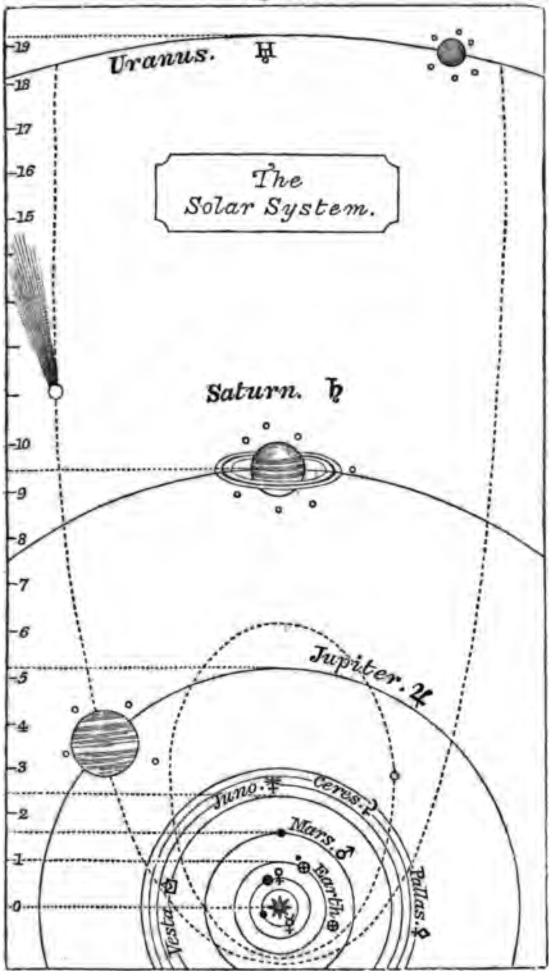
176. The satellites also, for the most part, revolve in the same direction as the planets—from west to east.

177. The satellites at present known are *eighteen* in number. The Earth has one, Jupiter four, Saturn seven, and Uranus six.

178. The COMETS also revolve round the sun ; but the paths they describe are elongated ellipses, or parabolas, remote from the circular form ; they are not always in the zodiac, as the most of the planets are ; and do not appear to be of the same solid substance as the primary and secondary planets. They have generally a somewhat fleecy or hairy appearance, from which the name "*comet*" has been applied to them, being derived from the Greek word "Κομη" (kome), signifying "hair."

179. The following figure, 11, represents the solar system , showing the comparative distances and magnitudes of the planets. In order that the whole may be included in a

Fig. 11.


The Solar System.
Uranus. ♅
Saturn. ♄
Jupiter. ♃
Juno.
Ceres.
Mars. ♂
Earth.
Vesta.
Pallas.
19
18
17
16
15
10
9
8
7
6
5
4
3
2
1
0

small space, and the leading proportions preserved, parts only of the paths of the more distant planets are shown. The sun, the centre of all, is placed near the bottom of the figure. Close around the sun is a small circle; this is the orbit of the planet MERCURY, and upon it is the astronomical sign employed to indicate that planet. The next circle, surrounding the former, is the orbit of VENUS, with her sign; then follows that of the EARTH. These three orbits are represented entire. Of the other orbits, part is cut off, less of each being shown as the planet's distance from the sun is greater. The name and sign of each planet are marked. The dotted straight lines from the upper part of each orbit to the scale at the side show, where they meet the scale, the comparative distances of the planets from the sun, and from each other. The first, marked 0, proceeds from the sun's centre; the second shows the earth's distance from the sun, the third that of Mars, the fourth that of Vesta, and so on. The numbers on the scale show at a glance the distances as compared with the earth's distance from the sun; as the distance between any two adjoining numbers is the same as that from 0 to 1, the earth's distance, which is thus taken as the unit of distance.

180. The curved dotted lines represent the orbits of comets. The smaller, which is complete, exhibits the orbit of the comet of BIELA. The other is introduced to illustrate the very elongated form of the orbits of some comets: it must not be regarded as accurate in its proportions.

181. It must be observed that while the proportionate distances of the planets from each other and from the sun are preserved, and also the proportions which the planets bear to each other in magnitude,—*the following proportions are not exhibited* in the figure, viz. the proportion of the magnitude of the sun to that of the planets, and the proportions of the magnitudes of the sun and planets to the various orbits. The sun's diameter is about ten times that of Jupiter, and less than one-eightieth of the diameter of the nearest planet, Mercury. The satellites also are too near.

182. The following figure (see Fig. 12) will convey some idea of the relative magnitudes of the sun and planets. The white line at the right is the sun's radius, or semidiameter; the figures next it represent the leading planets in the following order, commencing at the bottom:—Saturn, Jupiter, Uranus, the Earth, Venus, Mars, Mercury. The

Fig. 12.

two white circles in the middle of the figure exhibit the proportional magnitudes of the earth and the moon. The distances from the sun are shown at the left side. The radiated figure at the left corner at the bottom is the sun ; the white

dots at the lower ends of the white lines represent the planets, at their proportionate distances from the sun, the sign of each planet being at the other extremity of the white line.

183. The white lines exhibit the inclinations of the orbits of the planets to that of the earth; the lower or left-hand line representing the plane of the earth's orbit. These need not be attended to at present.

184. The proportion of the magnitudes of the sun and planets to that of the orbits is not exhibited in Fig. 12.

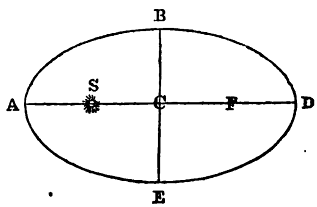
SECTION I.

GENERAL ASTRONOMICAL TERMS AND EXPLANATIONS.

185. ORBIT of a heavenly body. See Par. 169, page 35.

186. The EXCENTRICITY (from *ex*, out of, and *centrum*, the centre) of a planet's orbit is the distance from the centre of the ellipse in which it revolves to either of its foci (see Par. 51, page 15). In the adjoining figure, if A B D E represent the orbit of a planet or satellite, if C be its centre, and S F its foci, then the distance C F or C S will be the excentricity.

Fig. 13.



187. As the minor axis (B E, Fig. 13) of an ellipse increases, or the major axis decreases, the foci (S and F) draw nearer to the centre and to each other; the excentricity (C S or C F) lessens; and the figure approaches to that of the circle. When the major and minor axes are equal, the foci and centre coincide, and the figure is a circle.

188. In the case of the planets and satellites the two axes are nearly equal, the excentricity is small, and the

orbits, therefore, are nearly circular. In the orbits of the comets, the minor axis is considerably less than the major axis, the excentricity great, and the ellipse elongated. See figure of the solar system in page 37.

189. A planet's greatest distance from the sun is when it is at the extremity of the major axis farthest from that luminary—its least distance when at the other end, that nearest the sun. And the difference between the least and greatest distances will be twice the excentricity. In Fig. 13 above, if S represent the sun, a planet is farther from the sun at D than at A by S F, *i. e.* C S and C F, or twice the excentricity.

190. These two points in a planet's orbit, where it is at its greatest and least distances from the sun, are termed its APSIDES, from the Greek word αψις (apsis), the curvature or bend of an arch. The point furthest from the sun (D, Fig. 13) is termed the APHELION: the point nearest the sun, PERIHELION (A, Fig. 13):—from the Greek words ηλιον (helion), "the sun," ἀπὸ (apo), from, and περι (peri), around or near.

191. The ECLIPTIC is that great circle of the starry sphere in which the sun appears to move during the year; or the path through the heavens which the earth would appear to describe, if seen from the sun. It is called "ecliptic," because eclipses occur when the moon is on this circle. If Fig. 8, page 16, represent the sphere of the heavens, P the north pole, and *p* the south pole, the great circle H ♈ O ♎ represents the ecliptic. In Fig. 10, page 25, if N and S be the north and south poles, the straight line *a o* will represent the ecliptic.

192. The ZODIAC is a belt of the heavens, about eighteen degrees wide, embracing about nine degrees north and nine degrees south of the ecliptic. See Par. 131 and 132, page 29. It is called "zodiac" from the Greek word zodiakos, which is from Ζῶον "an animal," because the constellations which it included were mostly figures of animals.

193. The ecliptic is divided into twelve equal parts of 30° each, termed *signs*, or *signs of the Zodiac*; these are

numbered eastward in the heavens from the first point of the sign Aries, termed the EQUINOX, and usually marked ♈ in astronomical works.

194. The SIGNS of the zodiac are named by the same terms and in the same order as the CONSTELLATIONS of the zodiac, as in Par. 131, page 29: *but the signs and constellations of the same name do not correspond*—they differ by a whole sign, or 30 degrees. The SIGN ARIES is now in the *constellation Pisces*; the SIGN TAURUS in the *constellation Aries*; the SIGN GEMINI in the *constellation Taurus*; and so on.—See "Precession of the Equinoxes."

195. The ZENITH (an Arabic term) is that point of the starry sphere which is perpendicularly over the head of the observer.

196. The NADIR (an Arabic term) is the point of the heavens directly under the feet of the observer, and diametrically opposite to the zenith.

197. The HORIZON (from the Greek ὁρίζων, terminate) or *sensible horizon*, is the circle where the earth and sky appear to meet, bounding or terminating the view around us—the line which separates the visible from the invisible part of the sky.

198. The RATIONAL or *celestial horizon* is the great circle of the heavens parallel to the sensible horizon, but passing through the centre of the earth, and having the zenith and nadir for its poles: being 90° from each.

199. In Fig. 10, page 25, if the small black circle in the centre represent the earth, S a spectator on its surface, and the large circle Z N Q *n a* E the heavens, then Z would be his zenith, *n* his nadir, the dotted line *q v* the plane of his *sensible horizon*, and *a o* the plane of his *rational* or *celestial horizon*.

200. In relation to the heavenly bodies, the sensible and rational horizon may be reckoned the same, as the distance from the earth's surface to its centre is nothing compared with that from the earth to the sun, planets, or fixed stars.

201. The MERIDIAN, or *celestial meridian* of any place, is that half of a great circle of the heavens which passes

through both poles and through the zenith of the place. Its plane is always perpendicular to the horizon. It is called "meridian," because it is mid-day (*meridies*, Latin) when the sun is upon this circle.

202. The half of a great circle drawn round the earth, through its north and south poles, is also termed the MERIDIAN, or *terrestrial meridian*, of any place through which it passes. If the large figure in page 25 represent the earth, N and S its poles, then the semicircles N Z E S, N *e* S, N *d* S, N *c* S, N *r* S, are meridians.

203. The EQUATOR of a planet is a great circle round it, at equal distances (or 90°) from its poles. It is derived from the Latin, probably from *æquus* (equal), dividing the planet's surface into two equal portions.

204. The term is most usually applied in the case of the earth. The earth's equator is divided into 360 degrees. These are numbered by the British from the point where the meridian of Greenwich crosses the equator, and are reckoned east and west, the numbers increasing from 0° to 180° each way. They are reckoned either in distance or time—in degrees or hours; 15° corresponding to $1^{h.}$

If the figure in page 25 represent the earth, N and S its poles, then the line E Q will represent the equator, and the figures *under* E Q represent the division of it into degrees. If *o*, its middle point, be the point where the meridian of Greenwich crosses it, the degrees are numbered east and west from that point, as shown by the arrows.

205. The distance of any meridian, measured in degrees from that of Greenwich, is termed its LONGITUDE, or TERRESTRIAL LONGITUDE.

206. Parallels of Latitude are small circles on the earth's surface parallel to the equator, and whose planes of course are perpendicular to the earth's axis. Each parallel is named according to the number of degrees, measured along a meridian, which it is distant from the equator; and that distance is the LATITUDE of any place situated on that parallel; north latitude, or south lati-

tude, according as the place is north or south of the equator.

207. In Fig. 10, page 25, if E Q be the equator, then the curved lines *Z h*, 30 *c v*, *k o*, 15 *d* 15, *a r b*, 30 *e* 30, *m n*, &c., are parallels of latitude.

208. Thus, parallels of declination and hour-circles on the heavens correspond to parallels of latitude and meridians on the earth—declination to latitude—right ascension to longitude.

209. The circle which would be formed on the earth's surface, were it cut through by the plane of the ecliptic, is sometimes also termed "the ecliptic." If Fig. 8, page 16, represent the earth, P, *p* its poles, Q E is the equator, and H O the ecliptic.

210. The EQUINOCTIAL, or *celestial equator*, is the great circle where the plane of the earth's equator produced would cut the heavens. In Fig. 8, page 16, if P *p* be the poles of the heavens, the great circle Q *e* ♈ E ♎ is the equinoctial.

211. The EQUINOXES are the two points of the ecliptic in which it cuts the equinoctial. They are so called because the day and night are equal when the sun is in either of these points. The term equinox is from the Latin words *æquus*, equal, and *nox*, night.

212. In Fig. 8, page 16, if Q ♈ E ♎ be the equinoctial, and O ♈ H ♎ the ecliptic, the points ♈ and ♎, where these two great circles cut each other, are the equinoxes.

213. The SOLSTICES are the furthest north and furthest south points of the ecliptic. In Fig. 8, page 16, if P be the north pole, and *p* the south pole, then H and O are the solstices, H the northern solstice, O the southern. They are called solstices, from *sol*, the sun, and *sto*, I stand; as the sun apparently pauses in his course at these two points.

214. The TROPICS are two small circles round the earth, parallel to the equator, and 23° 28′ north and south of it. The northern is the TROPIC OF CANCER; the southern, the TROPIC OF CAPRICORN. The tropics are the parallels drawn through the north and south points of the ecliptic.

215. If Fig. 8, page 16, represent the earth, O H the ecliptic, and Q E the equator, the circles A H and O B, drawn parallel to the equator through the north and south points of the ecliptic, are the tropics. In Fig. 10, page 25, the dotted lines *k o* and *a b* represent the tropics. The tropics are so called from the Greek τρεπω (trepo), I turn, as the sun changes his course at the tropics.

216. The POLAR CIRCLES are two of the parallels round the earth, 23° 28′ from each pole. The northern is termed the ARCTIC CIRCLE, the southern the ANTARCTIC CIRCLE. The polar circles are represented by Z *d* T, R *v* N, in Fig. 8; and by Z *h* and *m n*, in Fig. 10.

217. AZIMUTH CIRCLES, OR VERTICAL CIRCLES, are great circles of the sphere passing through the zenith and nadir, and perpendicular to the horizon. In Fig. 8, if C be the position of a spectator, and O H his horizon, then the circle Z *h* N *m d* is a vertical or azimuth circle. If Q E be his horizon, P *d p v* would be his azimuth circle.

218. The ALTITUDE, height, or elevation of a heavenly object, is the number of degrees, minutes, &c. in the arc of the vertical circle between it and the horizon of the observer.—In Fig. 8, if the circle Q *e* E be the horizon, and *a* any celestial object, the arc *a e* is its altitude.

219. The AZIMUTH of a celestial object is the arc of the horizon intercepted between the vertical circle passing through the object, and the east or west point of the heavens. The term azimuth is of Arabic origin.

220. CULMINATE. A celestial body is said to culminate when it comes to the meridian of a place. The term SOUTHING is employed in a similar sense. The term *culminate* is from the Latin *culmen*, the highest point—as a celestial object is at its highest above the horizon when it culminates.

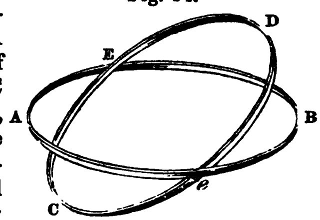
221. APOGEE is the point in a planet's orbit where it is furthest from the earth. PERIGEE the point where it is nearest to the earth. These terms are from γη (ge), the earth; ἀπὸ (apo), from, and περι (peri), near, or around.

222. POLES. The term pole is applied to the extremities of the earth's, or any planet's axis of rotation; and also to the two points in the heavens which are at the opposite extremities of the axis about which they appear to us to revolve. (See Par. 103.) These two points remain fixed while the others describe circles around them, as may be readily observed of the pole-star and any others.—The axis of our earth produced would pass through the poles of the heavens; so that these points are perpendicularly above the north and south poles of the earth.

223. The ELEVATION OF THE POLE (218) is the arc of the meridian intercepted between the pole and the horizon. It is equal to the arc of the vertical circle between the zenith of the place and the equator, or equal to the latitude of the place.

224. The NODES of a planet are the two points where its orbit cuts the plane of the ecliptic. In the adjoining figure, if EB*e*A represent the plane of the ecliptic, and ED*e*C the orbit of any planet, the points E and *e* are the nodes. The line joining the nodes is called the *line of the nodes;* a line from E to *e* would be the line of the nodes.

Fig. 14.



225. The node at which a planet crosses *to the north* of the plane of the ecliptic, is termed its *ascending node;* the point at which it crosses *to the south* of the plane of the ecliptic, its *descending node.*

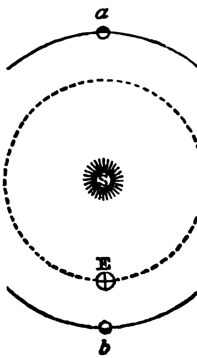
The term *node* is from the Latin *nodus*, applied to signify an intersection.

226. The INFERIOR planets are those which are nearer to the sun than the earth, as Venus and Mercury.—The SUPERIOR planets are those which are further from the sun than the earth, as Mars, Jupiter, Saturn, &c.

227. When two celestial objects are in the same me-

ridian, they are said to be in CONJUNCTION; when on the opposite meridians, they are said to be in OPPOSITION: or generally, they are reckoned in conjunction when on the *same side of the earth;* in opposition, when the earth is between them, and they are therefore on opposite sides of it.

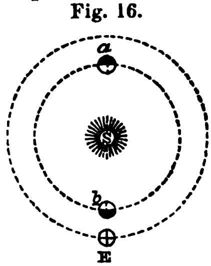
Fig. 15.



228. For example, when a superior planet, as Mars, is on the same meridian as the sun, the sun being between the earth and the planet, which appears in the same part of the heavens as the sun, the sun and planet are said to be in CONJUNCTION. Thus, in Fig. 15, if E be the earth, and *a* Mars, the sun and Mars would be said to be in CONJUNCTION. When the earth is between the sun and planet, so that they appear in the opposite parts of the heavens, that planet and the sun are said to be in OPPOSITION; as *b*, in the adjoining figure.

229. In the case of the inferior planets, when the planet is between the earth and sun, it is said to be in INFERIOR CONJUNCTION; when the sun is between the earth and planet, it is said to be in SUPERIOR CONJUNCTION. In Fig. 16, if E be the earth, and *a*, *b*, different positions of an inferior planet, it is in *inferior conjunction* at *b*, in *superior conjunction* at *a*.

Fig. 16.



230. Hence, when a planet is in conjunction, it rises and sets about the same time as the sun. When it is in opposition, it sets when the sun rises, and rises when the sun sets.

231. The DISC of a heavenly body is the face, or apparently broad flat surface which it presents to the eye.

232. The PHASES of the moon or a planet are the different appearances it presents, according as more or less of its illuminated surface is turned towards the earth, from the Greek word φασις (phasis), the appearance presented by a body.

233. The term TRANSIT is usually applied to the passing of Mercury or Venus between the earth and sun, appearing like a black spot on his disc. It is from the Latin *transitus*, signifying a passage or going over.

234. OCCULTATION (disappearing, or being hid) is the eclipse of a star or planet by the interposition of the moon or some planet, which intercepts our view of it.

235. Motion is said to be UNIFORM when its rate remains the same; ACCELERATED, when it becomes quicker every moment; RETARDED, when it becomes every moment slower. The MEAN MOTION of a planet is the rate at which it would go if it moved uniformly, still describing the same distance in the same time.

236. CENTRE OF GRAVITY. There is a certain point of every body, which bears such a relation to the whole mass, that the same effects would ensue from its gravity if its whole mass were concentrated in that point,—or if a force equal to its gravitating force acted at that point,—and a similar point may be found for any number of bodies connected together. Its nature is such, that if a plane pass through the centre of gravity of a body, or system of bodies, in any direction, there shall always be an equal portion of gravitating matter on each side of that plane.

237. A PENDULUM is any body suspended at a fixed point, about which it swings backwards and forwards. It performs its oscillations (vibrations) in equal times, and therefore is used for measuring time. As it is the force of gravity which causes its oscillations, these are more rapid the stronger the action of that force is; and accordingly it has been used as a measure of the strength of gravity. The vibrations of the pendulum are also more rapid as the rod is shorter (the time of each vibration being in proportion to the square root of

the length of the rod). At the latitude of London, 51° 30′ 47·59″ north, the length of pendulum which vibrates in one second is 39·138 inches, about 39⅛ inches.

ASTRONOMICAL CHARACTERS.

Signs of the Zodiac.

♈ Aries.	♌ Leo.	♐ Sagittarius.
♉ Taurus.	♍ Virgo.	♑ Capricornus.
♊ Gemini.	♎ Libra.	♒ Aquarius.
♋ Cancer.	♏ Scorpio.	♓ Pisces.

The Planets, &c.

☉ The Sun.	♂ Mars.	⚴ Pallas.
☿ Mercury.	⚶ Vesta.	♃ Jupiter.
♀ Venus.	⚵ Juno.	♄ Saturn.
⊕ The Earth.	⚳ Ceres.	♅ Uranus.
☽ The Moon.		

Miscellaneous.

☌ Conjunction, in the same sign, degree, minute, &c.
⚹ Sextile, when *two* signs distant.
□ Quartile, when *three* signs distant.
△ Trine, when *four* signs distant.
☍ Opposition, when *six* signs distant.
☊ North node.—☋ South node.

SECTION II.

GENERAL LAWS OF THE SOLAR SYSTEM.

238. Each of the heavenly bodies which compose the solar system (excepting the sun) performs two principal motions, one through space round some centre, termed

revolution in an orbit, or *orbitual motion*;* another, turning on itself round an imaginary line passing through the body, termed *rotation on its axis*. The sun itself has the latter of these motions.

239. These, which are the leading motions of the solar system, and the other subordinate phenomena which it presents, flow from the operation of certain FORCES, by which the heavenly bodies are actuated.

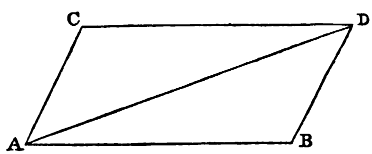
The term force is applied to express any thing that produces, or prevents, or changes motion, or tends to produce, prevent, or change motion.

240. A body actuated by a single force would, if that force were sufficient to impart motion to it, move on for ever in a *straight line*, in the direction of the force.

241. As the heavenly bodies move in *curved lines*, they must be acted upon by more than one force.

242. When *two* forces act upon a body at the same moment, it moves in a certain direction, which is found as follows. Let the forces be represented by two straight lines meeting in a point, whose directions represent the directions in which the forces act, and whose lengths represent the comparative intensities of the forces: complete a parallelogram having these two lines for sides. The diagonal drawn from the point where the lines meet will show the direction in which the body will move, and the force with which it will be impelled. If, in the following figure, the lines A B and A C represent the directions and comparative strengths of forces acting on a body at A, so that the force A C would, acting alone, carry it to C in the same time in which the force A B, acting alone, would car-

Fig. 17.



* The sun has not yet been proved to revolve round any centre, but it is most probable that it does, as it seems to have a proper motion.

ry it to B, it will arrive in that time at D, the other extremity of the diagonal, drawn from A, of the parallelogram A C D B, of which A B and A C are sides.

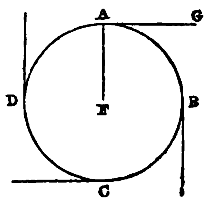
243. The finding the direction in which two or more forces impel a body is termed the "*Composition of Motion.*"

244. The direction which the body takes always inclines towards the direction of the greater force. Thus, in the above figure, the angle D A B is less than D A C, A B being greater than A C.

245. Two FORCES concur in imparting to the planets, comets, and satellites, their orbitual motions; first, a PROJECTILE, TANGENTAL, or CENTRIFUGAL force; second, an ATTRACTIVE, CENTRAL, or CENTRIPETAL force.

246. The projectile force, acting alone, would throw the revolving body out of its orbit, and cause it to move on for ever in a straight line. The direction of this line would be a tangent (see Par. 42, page 14, and Fig. 6, page 13) to the orbit at that point where the attractive force ceased and the projectile force alone acted on the body: or, would be in the direction which the planet had at the moment of quitting the orbit.

Fig. 18.



247. Thus, in the adjoining figure, let the circle A B C D represent the orbit of a planet, moving round in the direction from A towards B, B towards C, and so on. If, when at A, the attractive force were to cease, the projectile force would cause the planet to break off from the orbit and proceed on in the line A G, which would be a tangent to the orbit at A. At B, C, and D, were the projectile force alone acting, the planet would proceed in the lines drawn from these points in the figure. And in the whole course of its revolution, the planet has a tendency to break off in this manner.

248. This force, therefore, is termed *projectile*, as it tends to throw the body out of its orbit, and resembles the force with which any projectile is impelled from the surface of the earth. It is termed *tangental*, as it

tends to throw the body off in the tangental direction; and *centrifugal* (centre-flying), as it tends to impel it *from* the centre round which it has been revolving.

249. The existence of the projectile force is inferred from the phenomena of the orbitual motion of the planets; and its comparative intensity has been estimated. But no particulars as to its source or nature have been ascertained.

250. The projectile force in the solar system has sometimes been supposed to be connected with that great power of *repulsion* which seems to be universally diffused throughout the universe, which we know to be the antagonist of certain forms of the attractive energy, and with whose action we are familiar in the varied and interesting phenomena of Heat.

251. This centrifugal force, or tendency of a revolving body to fly off from the circle in which it moves, in the tangental direction, is well illustrated by the projection of the mud which adheres to a carriage wheel,—by the water being thrown out of a mop when it is rapidly whirled,—by the necessity which the equestrian galloping in a circular arena has to lean inwards when the speed is great, to overcome the tendency of his rapid motion to throw him outwards,—and very strikingly, in the manufacture of crown or window glass, in which a knob of glass is made to become a bowl of many forms, gradually spreading out, until it suddenly expands into a broad flat sheet.

252. The attractive force, acting alone, would draw the revolving bodies *inwards* from their orbits in the direction of the radius, and precipitate the planets and comets on the surface of the sun, and satellites on the primary planet round which they revolve.

Thus, if A, Fig. 18, be a planet revolving in the orbit A B C D, and the projectile force were suspended at A, the planet would move to the sun in the direction A F.

253. The attractive force thus prevents the projectile force carrying the planets out of their orbits into free space.

254. This power is termed *attractive*, as it tends to

draw the planets, &c. towards each other; *central*, or *centripetal* (centre-seeking), as it tends to impel them towards the centre round which they revolve.

255. In giving the planets their orbitual motions, these two forces act on the principle of the composition of motion (Par. 243). Any curved line may be considered as made up of a number of infinitely small straight lines, which will be the diagonals of a series of parallelograms, whose sides will be lines in the directions of the projectile and attractive forces at each point, and of lengths proportionate to the intensities of these forces. As the directions of the tangent and radius change at every step, the body enters every moment upon a new diagonal, the series of which will form the curve which it describes.

256. The form of the curve which the revolving body describes will depend upon the proportionate intensities of these two forces; but, in any case, it has been shown to follow, from the nature of the attractive force, that it will be one of the curves called conic sections, viz. a CIRCLE, an ELLIPSE, a PARABOLA, or an HYPERBOLA.

257. The attractive force seems to be the same as that well-known power, distinguished on our planet as the FORCE OF GRAVITY, which causes bodies to fall to the ground when left unsupported in the air, and which makes them exert on bodies beneath them the pressure which we term WEIGHT.

258. When spoken of with respect to its action throughout the solar system, it is termed attraction of gravitation, or, simply, GRAVITATION.

259. Three things may be noted with respect to GRAVITATION. 1. That it acts in all directions, spreading its influence out from a body like rays of light from a luminous object. 2. That its force is in direct* proportion

* When one thing alters in a certain way in the same proportion in which another alters in the same way, this is termed *direct* proportion. Thus, in the above instance, if the quantity of matter *diminishes*, the force of attraction *diminishes* as much. When one thing alters in a certain way in the same proportion in which another alters in the opposite way, this is *inverse* proportion.

tion to the quantity of matter (*i. e.* to the MASS) in the attracting body; 3. That its force is in inverse* proportion to the square of the distance.

260. That gravitation acts in all directions is shown by bodies floating on water gathering together in heaps, —by a plummet suspended near the top of a high precipice leaning towards the rock,—by bodies tending towards the earth on every side,—by the action of the moon in raising the waters of the ocean, and forming the tides,—by the mutual action of the sun, planets, and satellites,—and by the consideration that, as attraction of gravitation seems an inherent property of matter, there seems no reason why it should act in any one direction and not in every other.

261. The predominating direction of gravitation on the earth's surface is towards the centre of the earth, solely because there is so much more matter very near to us in that direction than in any other. The difference between the earth and the bodies on its surface, in respect to the force of gravitation, is a difference in *degree* only, not in *nature.* This was proved very satisfactorily by CAVENDISH, who found that large leaden balls exerted a sensible attraction on small leaden balls at the end of a light rod, suspended at the middle by a slender thread.

262. That the force of gravitation is in direct proportion to the quantity of matter is shown, by the attractive force of two portions of the same kind of matter being in proportion to the quantities of it which are taken, as in Cavendish's experiments (261).

263. As, in the same kind of matter, attraction is in proportion to the quantity, it is inferred that, among different kinds of matter, the quantity of matter is greater where the attraction is greater. On this supposition is founded the general rule, that the force of gravity is in direct proportion to the quantity of matter—quantity of matter meaning gravi-

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Thus, in the above instance, if the square of the distance between two bodies *diminishes*, the force of attraction between them *increases* as much as the square of the distance has diminished.

* See note, preceding page.

tating force. The quantity of matter, in this sense, in any body, is termed its MASS.

264. That the force of gravitation is in inverse proportion to the square of the distance, is a mathematical deduction from the elliptic form of the orbits of the planets, with the sun in one focus: following, therefore, from the second law of KEPLER.

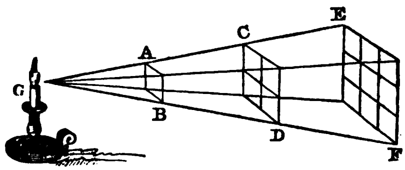
265. That gravitation has force in *inverse proportion to the square of the distance*, signifies, that the attraction of one body for another, when placed at different distances, is as much *greater* as the square of the distance is *less;* and as much *less* as the square of the distance is *greater*. This is illustrated by the following table, where the first two columns represent different distances, —the next two, the proportionate forces of attraction at these distances, in squares,—and the two last, the value of these squares expressed in numbers.

Attraction		Attraction							
at 1	*is to*	at 2	*as*	2^2	:	1^2,	*as* 4	:	1
2	...	... 5	...	5^2	:	2^2,	... 25	:	4
2	...	... 1	...	1^2	:	2^2,	... 1	:	4
3	...	... 7	...	7^2	:	3^2,	... 49	:	9

Thus, if the two bodies be first at a distance of 1, and then of 2, the proportionate force of attraction exerted by one body will be 1 at the distance of 2, 4 at the distance of 1. If they be at distances of 3 and 7, the attraction at 3 will be 49, while that at 7 will be 9.

266. The diminution in the above proportion of an influence radiating from a central point, may be illustrated by the following figure. Let G represent any luminous body, A B, C D, and E F, boards at the same successive distances as A B from G, A B being at one, C D at 2, E F at 3. The same quantity of light which spreads over A B will, at CD, *twice* the distance, spread over *four* times the surface; at E F, *thrice* the distance, spread over *nine* times the surface. But the same amount of light, when diffused over four times the space, will only have *one-fourth* the intensity—over *nine* times the space, one-ninth of the

Fig. 19.



intensity. Hence, the light at 1 *is to* that at 3 *as* $3^2 : 1^2$, as $9 : 1$, or as $1 : \frac{1}{9}$;—that is, inversely as the squares of the distances.

267. From the general phenomena of attraction and of the solar system, it is inferred that every particle of matter attracts every other with a force directly proportional to the mass, and inversely proportional to the square of the distance.

268. It is known that this universally diffused power extends to the utmost limits of the solar system. We have reason to believe, from the phenomena of binary stars, that it also prevails among the fixed stars. It is also probable that, as well as acting between the *parts* of each system, it extends between the various systems, connecting them in one grand chain. And, there is reason to suppose, that its various forms, as exhibited on our globe,—gravity, cohesion, chemical attraction, electric and magnetic attraction,—are merely varieties of one fundamental power.

269. Few things are more striking than that invisible and mysterious connexion which subsists between the separate particles or masses of matter—drawing or binding them towards each other—acting with such enormous power, and at such immense distances as in the central force which, spreading from the sun in all directions, preserves the planets in their orbits, at distances of hundreds of millions of miles, and perhaps preserves *systems* in their proper positions, at distances measured in millions of millions of miles—drawing a stone or drop of rain to the ground—causing the rain or dew drops to form into globules like suns and planets in

miniature—binding the particles of iron to each other with the force which enables it to bear such prodigious strains—aiding in producing the singular phenomena of electricity and magnetism—and, lastly, in its action between different bodies, giving rise to the phenomena of chemistry, and creating the innumerable and ever-varying combinations which surround us on every side.

270. It has been inferred from astronomical phenomena, that the action of gravitation is either instantaneous, or that its velocity is at least *fifty million times* greater than that of light (Par. 80); and also, that it penetrates freely through the densest bodies and acts on another body, without any diminution of its energy.

271. The sun, planets, and satellites, are collections of particles, each obeying the general laws of attraction given above (Par. 259). And the attractive force of each orb in the solar system is found to act upon the others, exactly as if its whole matter were collected into one particle, situated at its centre of gravity, and possessing the aggregate force of the mass.

272. The true centre of the planetary motions is not the sun's centre, but the centre of gravity of the solar system. This point, however, owing to the enormous mass of the sun, is a very short distance from his actual centre. In like manner, the centre of gravity of the earth and moon is the centre of the moon's motion, and is also the point which is to be regarded as moving round and attracted by the sun.

273. The following general laws, developed by Kepler, are found to prevail throughout the solar system:—

I. *The planets move round the sun in such a manner, that the line drawn from a planet to the sun passes over areas proportional to the times of the motions.*

II. *Each planet describes an* ELLIPSE, *having the sun in one of the foci.*

III. *The squares of the periodic times* of the planets are in the same proportion as the cubes of their mean distances from the sun.*

274. The first of KEPLER'S LAWS is shortly expressed

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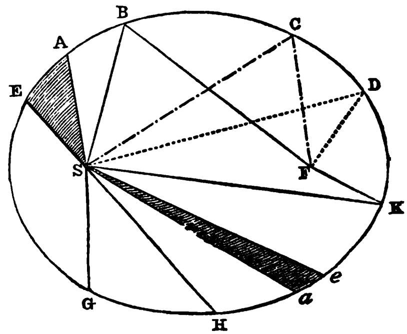
* Periodic time—the time occupied by any body in completing one revolution in its orbit.

as follows:—"The radius vector of a planet describes areas proportional to the times."

275. This will be illustrated by the following figure.

Fig. 20.



The *radius vector* of a planet is an imaginary straight line passing from the sun to the planet, supposed to remain fixed at the former, but to follow the planet in its course round that orb, expanding or contracting according as the planet is further from or nearer to the sun.

276. In the above figure, let S be the sun, and A, E, G, H, *a*, *e*, successive positions of a planet; then, S A, S E, S G, S H, S *a*, S *e*, will be the radius vector in these several positions. Now, let it be supposed that the planet moves from A to E, in the same time in which it moves from *a* to *e*:—it would then be found, that the radius vector, in passing from S A to S E, has traversed the same space as in passing from S *a* to S *e*; that is, that the shaded area S A E is equal to the shaded area S *a e*; or, as expressed above, that the area S A E bears the same proportion to the area S *a e*, as the time of the motion from A to E does to the time of the motion between *a* and *e*; i.e. *that the areas are proportional to the times* —(equal in the instance just given, since the times were supposed equal).

277. In like manner, if the area S E G be equal to the area S G H, the planet will move from E to G in the same time as from G to H. And any area, S G H, will bear the same proportion to any other area, S H K, as the time in passing from G to H does to the time in passing from H to K.

278. Hence, then, a planet does not move round the sun at a uniform rate; but its motion is at one time accelerated, at another, retarded.

279. For, as the planet is at different distances from the sun, and its radius vector describes equal areas in equal times, any area when the planet is near the sun, must be broader than an equal area when the planet is remote: the part of the orbit which bounds the broad area must be longer than that which bounds the narrow one; and as they are both described in the same time, the planet must move faster in that nearest the sun.

280. The velocity of a planet is least when furthest from the sun, becomes accelerated as it comes nearer, is at its highest when the planet is nearest to the sun, and becomes retarded as its distance from the sun increases.

281. The velocity of a planet in different parts of its orbit is in inverse proportion to the square of its distance from the sun.

282. From this law, that the areas described by the radius vector are proportional to the times, the conclusion was drawn by NEWTON that the power by which the tangental force of the planets is neutralized, is directed towards the sun.

283. The second of KEPLER'S LAWS is, that "the orbits of the planets are ellipses, with the sun in one focus."

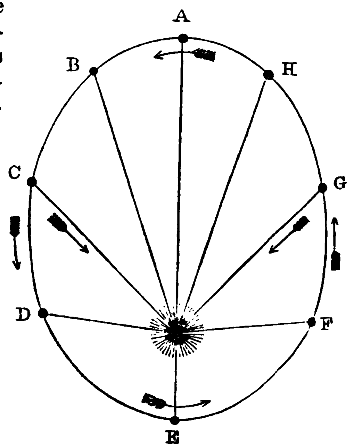
284. Although the planets and comets, from the elliptical form of their orbits, are nearer the sun at one time than another, and his action on them is so much stronger as they are nearer, they do not from this continue to draw gradually nearer and nearer, so as at last to fall to that body: nor, when they are remote, and his action is weaker, do they recede from him altogether. That they do not do

so is still more striking in the case of the comets, which are so very far from the sun at one time, and so near at another.

285. The planets and comets do not fall to the sun, because, when they approach nearer to him, so that his attraction is stronger, the tangental force becomes stronger at the same time:—and they do not fly from the sun altogether, because while they recede from him, the tangental force at the same time diminishes in energy.

286. That this is the case will be illustrated by the following figure. Let this figure represent the orbit of a planet, A—S being the sun. Let the planet be in its aphelion at A. It is there under the influence of the attractive and projectile forces, whose united operation brings it to B. Being there nearer to the sun, it is more powerfully attracted and drawn still nearer to him; and, as *the attractive and projectile forces are operating in the same direction*, the velocity is increased,

Fig. 21



proceeding from B to C, a greater distance, in the same time in which it passed over the shorter distance from A to B. At C, being nearer than at B, the attractive energy is further increased, and as this still concurs in direction with the tangental force, the velocity is augmented. This goes on till it comes to its *perihelion* at E, where its velocity is greatest. The great projectile force thus acquired prevents it going still nearer, overcomes the increased attractive force, and causes it, at E, to begin to increase its distance, which it does, step by step,

from E towards A, in the reverse order to that by which it had lessened its distance. The attractive force decreases rapidly as the distance increases; but the projectile force also diminishes, *as the sun's attraction is now acting nearly directly against the projectile force,* and it thus lessens its impetus at every step. By this, in progressing from E to F, G, H, the projectile force is so much weakened that the attraction of the sun overcomes it in turn, and bends the planet's course towards A; where, when it arrives, the same series of actions commence again.

287. That the attractive and projectile forces act *together* as the planet passes from its aphelion to perihelion, and *against each other* when it is proceeding from perihelion to aphelion, is shown by the directions of the arrows.

288. It is from the revolution of the planets in elliptical curves, with the sun in one focus, that the great law of attraction has been deduced—that its force is in inverse proportion to the square of the distance.

289. The third law of KEPLER establishes an interesting relation between the distances of the planets from the sun and the periods in which they complete their revolutions round him—namely, that "the squares* of the periods are proportional to the cubes* of the distances."

290. That is, the square of the number of days any planet takes to go once round the sun, bears the same proportion to the square of the number of days any other planet takes to complete its revolution round the sun, as the cube of the distance of the first planet from the sun bears to the cube of the distance of the second planet from the sun.

291. Or, in the case of Venus and the earth,

square of		square of		cube of		cube of
224·8	:	365·25	: :	69	:	95

* The SQUARE of a number is the number produced by multiplying the number by itself: the CUBE of a number is the product obtained by multiplying it twice by itself. Thus, 9 is the square of 3, 27 the cube of 3; 4 the square of 2, 8 the cube of 2; 25 the square of 5, 125 the cube of 5.

The first number expresses the number of days occupied by Venus in her revolution round the sun; the second, the number of days the earth takes to go round the sun; the third number is the distance of Venus from the sun, expressed in millions of miles; the fourth, the distance of the earth from the sun in millions of miles.

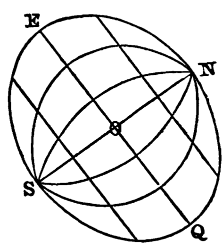
292. The sun, planets, and satellites, ROTATE, or turn upon themselves in regular periods. The time in which this rotation is completed is called the DAY of the revolving body; the imaginary line about which it turns, the AXIS; and the two extremities of this line, the POLES. They are known to have this rotatory motion by the motion of spots upon their discs; and, by observing the time a spot takes to move through any arc, the time of a complete rotation is ascertained.

293. The sun and planets are of a globular form, but not perfect spheres (52). They are OBLATE SPHEROIDS (63). The flattening is at the poles, or opposite extremities of the axis, and is sometimes termed the "polar compression."

294. This flattening is most remarkable in Jupiter, in which it is so great as to give to that planet a distinctly oval shape.

295. The spheroidal form of the sun and planets is represented, considerably exaggerated, in the adjoining figure, where N S is the axis or polar diameter, and E Q the equatorial diameter.

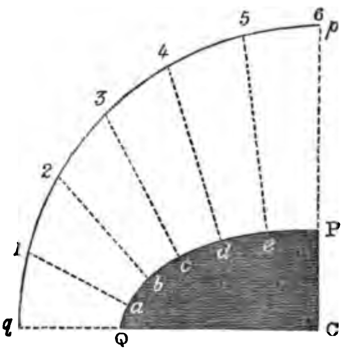
Fig. 22.



296. The spheroidal form of the sun and planets is most probably caused by their rotatory motion, which has a tendency to produce a flattening at the poles and bulging out at the equatorial regions; even though they had at first been formed perfectly spherical.

297. In the case of the earth, this polar compression is proved by the slower vibration of the pendulum in passing from the poles to the equator (307); and by the increase in the length of the degree of latitude in passing from the equator to the poles: so that one degree is not exactly one 360th part of a meridian. Let P Q represent the earth's surface from one pole to the equator, and *p q* the corresponding arc of the heavens, *p* being the pole of the heavens and *q* the equinoctial, 90° distant from the pole. Let the arc *p q* be divided into six equal arcs, of 15 degrees each; then, the places on the earth at which these degrees are vertical, would be the corresponding degrees of latitude on the earth: but it is evident from the figure, in which the lines *a* 1, *b* 2, *c* 3, *d* 4, &c. are perpendicular to the earth's surface, that the distance between the two adjoining points increase as we pass from the equator to the poles; or that a degree of latitude is longer in proportion as the distance from the equator increases. The measurement of degrees at different latitudes was one of the modes by which the spheroidal form of the earth was ascertained.

Fig. 23.

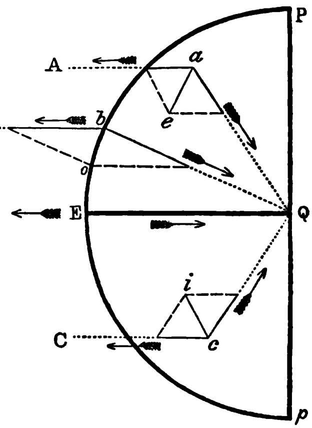


298. In consequence of the rotatory motion, the parts at any distance from the axis have a considerable centrifugal force, or tendency to fly off in the tangental direction, and they would do so, if the parts were not held together by a firm attractive force; or if the centrifugal force were sufficiently strong. But, by the planets' attraction, they have also a tendency towards the centre, in the direction of the radius. Under the action of these two forces, by the laws of the composition of motion, they tend to a middle course, which brings

them from the poles towards the middle regions, and causes an accumulation in that quarter.

299. This is illustrated by the following figure. Let P *p* be the axis of any planet P *b* E *p*, and *a*, *b*, *c*, any particles, at some distance from the axis; E, the equator; E Q, the equatorial diameter. Let it be supposed that the direction of the planet's motion is from Q towards E, and that the planet is in a fluid or semi-fluid state, so that it is capable of having its form changed by any force. Each of these particles will have a tendency to pass towards the equator—a tendency both directly outwards and towards the equator. The particle *a* will have a tangental force impelling it outwards in the direction *a* A, and a central force towards Q, in the direction *a* Q. By the laws of motion (242) it will tend towards the middle course *a e*. In like manner the point *b* will tend in the direction *b o*; and a point *c*, on the other side of the equatorial diameter, outwards and towards the equator, in the direction *c i*.

Fig. 24.



300. By these forces it is at once evident that the particles would be brought from the polar regions towards the equatorial, if in the fluid state. But even were a planet, such as the earth, with large portions of its surface covered with water, mainly in the solid state and perfectly spherical, a rotatory motion would cause a polar compression. For, the parts at the surface *in the liquid form* would be thrown towards the equatorial regions, and heaped up there, while the polar regions would be left dry. And, as the parts at the surface are elevated by volcanic heat, and thus to a certain extent moveable, and the earth is continually worn

down by the action of disintegrating agents, diffused through the waters, and thus rendered loose and moveable, subsiding afterwards and filling up the lower parts of the deep seas, the excess of land at the polar regions might be in time removed, spread out over the equatorial districts, and thus an equal distribution of land and sea take place over the whole. But from the geological structure of the earth, this is not supposed to have been the mode of formation.

301. In the case of the earth, it is probable from geological considerations, that the spheroidal form was assumed while it was mainly or entirely in the fluid state; the opinion being held that the earth was formerly, and is perhaps now in part, fluid.

302. The rotatory motion of a planet affects the force of gravity at different parts of its surface. It lessens the force of gravity in the equatorial regions, rendering it proportionally stronger towards the poles. Two causes contribute to this,—the rotatory motion, and the spheroidal form.

303. Wherever there is rotatory motion, the parts revolve in larger circles in proportion as they are further from the axis, and therefore move most rapidly, and with greater force. And as the distance from the axis increases from the poles towards the equator, the parts will have greatest centrifugal force in proportion as they are furthest from the poles. But the centrifugal force acts in opposition to gravity; the latter force, therefore, is more resisted towards the equatorial regions, and produces a less effect there.

304. The spheroidal form of the planet also lessens the force of gravity about the equatorial regions; the parts there being further from the centre. Hence, even though the planet did not rotate, if it had the spheroidal form, the force of gravity would be somewhat greater at the flattened than at the projecting parts.

305. Thus, directly, and indirectly in causing the spheroidal form, the rotatory motion is the source of the differences of the force of gravity.

306. Accordingly, it is actually found that a body

weighs less, or produces less downwards pressure in proportion as it is nearer to the earth's equator,—that its gravity increases as we approach either pole.

307. This difference in the force of gravity at the poles and middle regions, cannot be manifested by a common balance, as the weights used would be as much affected as the body to be weighed. But it is at once detected by a spring balance, or by the pendulum. The spring is less stretched by the same body in proportion as the distance from the pole is greater:—and the pendulum vibrates slower (Par. 237),—both of these circumstances indicating a diminution in the force of gravity.

308. The solar influences which give rise to heat and light, obey the same law with respect to their strength at different distances, as gravitation, *i.e.* inverse proportion to the square of the distance. Thus, the distance of Mercury being 37 millions of miles, and that of the earth 95 millions of miles, the following proportion will hold:—

Sun's influence at Earth : *Sun's influence* at Mercury, *inversely* as $95^2 : 37^2$, *directly* as $37^2 : 95^2$; as $1369 : 9025$, or as $1 : 7$

Thus, the sun's influence at Mercury is nearly seven times what it is at the earth.

309. But it must not be inferred from this, that the temperature at the different planets is in exact proportion to the sun's influence; for temperature is dependent not only on the amount of the heating agent, but on many circumstances in the nature of the body acted on. This is illustrated on our own planet, where, owing to the increasing rarity of the air, as the elevation is greater, the solar rays produce less effect in proportion as the height above the level of the sea increases.

310. As there are so many bodies in the solar system, all mutually attracting one another, their influence on each other causes several slight deviations from the

simple laws just laid down: Several of the more important of these inequalities will be noticed in another part of this work, under the heads Nutation, and Precession of the Equinoxes.

SECTION III.

OF THE SUN, PLANETS, SATELLITES, AND COMETS.

I.—THE SUN.

Sol, or ⊙.

311. The sun is the centre of the solar system, and is found to be a globular body of immense magnitude.

312. Its *mean* distance from the earth is about ninety-five millions of miles (95,000,000). But the earth is nearly three millions of miles nearer to the sun in our winter than in our summer.—See Earth, and Seasons.

313. The sun is not perfectly spherical; but, like all the planets, is flattened at the two opposite points, termed poles. Its form is, therefore, a spheroid, like an orange.

314. The sun's diameter is about eight hundred and eighty-two thousand miles (882,000):—or $111\frac{1}{2}$ times that of the equatorial diameter of the earth.

315. The magnitude (or, volume) of the sun is to that of our earth as 1,384,472 to 1.* That is, the sun is extended through 1,384,472 times the space occupied by the earth.

316. The gravitating force, or mass, of the sun is to that of the earth as 354,936 to 1. As the sun exceeds the earth so much more in bulk than in weight, the density† of the sun must be less than that of the earth: the sun's density

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* The magnitudes of spheres are as the cubes of their diameters, —that is, in the present instance,

Magnitude of earth : Magnitude of sun :: $1^3 : 111\frac{1}{2}^3$ :: 1 : 1,384,472

† Specific gravity, or comparative quantity of gravitating matter in the same volume.

is a little more than one-fourth of that of the earth, or as 0·2543 to 1.

317. Hence, owing to the comparatively low gravitating force of the sun's matter, and the distance from the surface to the centre, the force of gravity at the sun's surface is only 27·9 times that at the earth's surface. A body, therefore, which at the earth's surface would compress a spring to an extent indicating a weight of one pound, would, at the surface of the sun, compress that spring as much as 27·9 pounds would at the earth's surface.

318. The sun rotates upon its axis in a little more than twenty-five days, in a direction from west to east. This is ascertained by observation of the motion of the spots on his surface. These are found to disappear on one side, while others appear on the opposite side, move round in the same direction, and disappear in their turn on the same side as the former. The uniform progressive motion of the spots, at the same rate, and in the same direction, can only be explained by a rotatory motion of the body of the sun in that direction.

319. Further, the flattening of the sun at the poles is a confirmation of the opinion that it rotates, as we know that this form is produced by rotation.

320. The sun's axis is not perpendicular to the plane of the earth's orbit: it leans 7° 20′ from the perpendicular; forming therefore an angle of 82° 40′ with the plane of the ecliptic.

321. It is supposed that the sun is not fixed to one spot, but that it has a *proper motion*, as it is termed, through space, carrying the planets, &c. along with it. This inference was drawn by SIR WILLIAM HERSCHEL, from observing that the principal stars seemed to have a gradual motion *from* the constellation Hercules, and were becoming more open or spread out in that quarter—which he considered might be explained by a motion of the solar system towards that constellation.

322. The sun has two *apparent motions*, one daily through the sky, giving rise to the alternations of night and day; another yearly through the constellations of

the zodiac, causing its different degrees of elevation above the horizon at different periods of the year. These apparent motions of the sun are caused, the first by the rotation of the earth on its axis, the latter, by the earth's annual revolution round the sun.—See Earth, and Seasons.

323. The sun is considered to be opaque in its body, but to be surrounded by a highly luminous atmosphere, from which emanate the rays that cause light and heat when they strike upon bodies.

324. Viewed through a telescope, the sun presents a somewhat mottled appearance, with minute shady spots scattered through the luminous matter. Large dark spots, which are not permanent, and which change both in size and form, are seen upon its surface. These are termed MACULAE: they consist of a dark or black part in the centre, called *nucleus*, with a surrounding part not so dark, termed *penumbra*. In the vicinity of the spots, brilliant and highly luminous streaks are seen: these are named FACULAE.

325. The maculae are found only about the equatorial regions of the sun. Their magnitude is very various—from a few hundred to upwards of forty thousand miles.

326. Various theories have been formed regarding the maculae. It has been supposed that the surface of the sun is in a state of combustion, and that the spots are *scoriae* or *scum*, or ashy matter floating on the surface. They have been thought to be cavities in the body of the sun, the nucleus or dark part being the bottom of the cavity, and the penumbra or shady part its sloping sides. They have also been conjectured to be the smoke of solar volcanoes.

327. The opinion most generally entertained at present is, that the spots are parts of the dark body of the sun exposed to view in consequence of breaks or gaps in the luminous atmosphere which is believed to surround the body of the sun. The *penumbra* is supposed to be caused by portions of an inner non-luminous atmosphere, in which the gap is not so wide as in the external luminous

one: for, when a spot disappears, the nucleus contracts, and disappears before the penumbra, as if the gap in the inner atmosphere had filled up first.

328. The sun is thus supposed to have two atmospheres; —one, transparent, but not luminous, next the body of the sun; and an external atmosphere, highly luminous, and at an elevated temperature, which is the source of the light and heat which the sun diffuses. The inner atmosphere, if there be two of the nature just described, probably rises into the other, and causes the mottled appearance alluded to above (324).

329. The *faculae* are supposed to be the elevated parts or ridges of waves in the external luminous atmosphere.

330. Nothing positive is known of the source of the sun's light and heat. They have been conjectured to be caused by minute particles of the sun's substance discharged from it; but this theory, besides the improbability of a continual loss of substance without any diminution of brilliancy, is not considered to explain satisfactorily the phenomena of light and heat. The opinion now most generally entertained is, that light and heat are to be attributed to *vibrations* or *undulations* in a thin fluid diffused throughout space, which is supposed to be excited by the presence of luminous and hot bodies, into undulations, capable of causing impressions of light and heat on bodies which they meet: that the sun causes these undulations in this ethereal fluid, which being propagated through space in waves, cause heat and light on the surface of the planets.

II.—THE PLANETS AND SATELLITES.

331. There are Eleven Planets, accompanied by Eighteen Satellites, in the solar system.—See Par. 174, where they are named in the order of their distances from the sun.—See also Fig. 11, page 37.

332. Though the planets appear as mere points to the naked eye, they present discs of considerable breadth

when viewed through telescopes, even of very moderate magnifying power.

333. This affords a very striking illustration of the remoteness of the fixed stars: an ordinary telescope magnifies a planet into a perceptible disc, or breadth of surface; but the fixed stars, viewed by the most powerful telescopes, still appear as mere luminous points.

334. The part of any planet which is turned towards the earth will always be *one-half of its spherical surface*, and it will appear as a flat circular surface when the whole of the part next us is visible, just as the sun and full moon appear: while, if less than the whole of the half next us be visible, the planet's disc will be proportionately less; and not of a circular form.

335. The planets and satellites do not shine by their own inherent light, but by reflecting the light which they receive from the sun. This is known by the PHASES which they present: for a planet varies in the magnitude of the illuminated surface which is turned towards us; and it is found that, *of the side which is next us, that part only appears luminous which is at the same time turned towards the sun, so as to receive his light.*

336. As already mentioned, the sun and planets (excepting the asteroids) all lie nearly in one plane, their orbits forming very small angles with the plane of the ecliptic; from which, they always appear in that belt of the heavens in which the sun travels during his apparent annual course through the starry sphere, called the Zodiac.

(1.) *The Planet* MERCURY, ☿.

337. This is the nearest of all the planets to the sun, so far as is yet known. His mean distance from the sun is about thirty-seven millions of miles (37,000,000). His orbit is rather more elongated than is usual among the planets; his excentricity (Par. 186) being more than a fifth of his mean distance from the sun. He will

thus be at one time 2-5ths of his mean solar distance nearer to the sun than at another.

338. Mercury is the smallest of the planets, excepting the asteroids. His diameter is a little less than 3200 miles —correctly, 3174 miles.

339. Mercury rotates upon his axis in 24 hours, 5 minutes, and a few seconds. He completes his course round the sun in nearly 88 days—correctly, 87 days, 23 hours, 25 minutes; moving in his orbit at the amazing rate of 30 miles in a second, or 1800 miles in a minute.

340. The orbit of Mercury is inclined about seven degrees to that of the earth: that is, there is an angle of 7° at the intersection of the planes of their orbits (28). —See Fig. 12, page 39, where the horizontal line (viewing the figure sideways) represents the plane of the ecliptic, and the line with the sign of this planet affixed, shows the direction of the plane of Mercury's orbit.

341. This planet can be seen by the naked eye, but very seldom, and only for a short time. Being so near to the sun, he is always in that part of the sky close around the sun, and his inferior light is lost amid the sun's rays. He never departs above 29° from the sun; and when he is visible, can only be seen for a little before sunrise, and a little after sunset.

342. Mercury occasionally passes directly between the earth and sun; appearing then as a black spot traversing the sun's surface. This is termed a *transit of Mercury over the sun's disc.* This is a rare occurrence, however; taking place at intervals of 6, 7, 13, 46, and 263 years. The reason of this phenomenon being so rare is, that the plane of the orbit of Mercury is not coincident with that of the earth; so that one-half of Mercury is above, the other half below the plane of the ecliptic. Consequently, the sun, earth, and Mercury, can only be in the same straight line, when the two latter are in the line of intersection of the planes of their orbits (line of the nodes), that is, when Mercury is in his nodes.

343. Mercury, as seen through a telescope, does not

always appear of the same size and form. He has phases, like the moon, being sometimes horned, like the new moon, sometimes full, like the full moon. The cause of these changes is this:—We can see only that part which is illuminated by the sun; and as different quantities of that part are turned towards us successively, we see different amounts of the illuminated half at different times.—See Moon's Phases.

344. At Mercury, the sun will present a diameter about three times greater than at the earth,—correctly, as 82½ to 32. And he will receive about seven times as much of the influence which, emanating from the sun, gives rise to the phenomena of heat and light (308, 309).

(2.) *The Planet* VENUS, ♀.

345. This planet is the second in order from the sun, her orbit lying between those of Mercury and the earth. Her mean distance from the sun is a little less than sixty-nine millions of miles (69,000,000); about 68,590,000 miles. Her distance from the sun does not vary much, her excentricity being only 1-147th of her mean distance from the sun.

346. The diameter of Venus is about 7700 miles,—correctly, 7727 miles. She is very little less than the earth, the diameter of the latter being only 200 miles more.

347. Venus rotates upon her axis in 23 hours 21 minutes; and completes her course round the sun in 224 days, 16 hours, and 49 minutes;—moving at the rate of 23 miles in a second, or 1380 miles in a minute.

348. The orbit of Venus is inclined about three degrees twenty-four minutes to the ecliptic (3° 24′): so that the plane of the earth's orbit and that of this planet are nearly coincident.

349. Venus is visible frequently. She is the most beautiful of the planets, whence her name, and, being near to us, she appears as bright and large as Jupiter, although that planet exceeds her very much in magnitude. Venus is seen only about the times of sunrise and

sunset; but is visible for a much longer time before sunrise and after sunset than Mercury, departing much further from the sun than that planet can do,—namely, to a distance of forty-seven degrees (47°) from that luminary. When seen before sunrise, Venus is well known as *Phosphorus*, *Lucifer*, or *the morning star;* when she appears after sunset, she is termed *Hesperus*, *Vesper*, or *the evening star*.

350. The *transit of Venus over the sun's disc* is a rare occurrence, for the same reasons assigned above for the rare occurrence of the transit of Mercury. The transit of Venus takes place alternately at intervals of 8 and 113 years. The last was in 1769, the next will be in 1874, and there will be another in 1882.—This phenomenon is of great use in practical astronomy. It has been taken advantage of to aid us in determining exactly the sun's distance.

351. Venus exhibits phases, as Mercury and the moon do; and for similar reasons.

352. At Venus, the diameter of the sun appears about one-half greater than at the earth,—correctly, as 44 to 32. And the sun's influence at Venus is about double of what it is at the earth.

353. The axis of this planet leans very much towards the plane of her orbit, forming with it an angle of 15 degrees; that is, inclining 75 degrees from the perpendicular. Her tropics (372) are therefore only 15 degrees from her poles, and her polar circles only 15 degrees from her equator. This gives rise to some striking peculiarities in the constitution of Venus: namely, that there is much greater diversity of seasons than prevails on the earth,—that the days are much longer where it is summer, and much shorter where it is winter,—that a larger proportion of the regions about the poles have perpetual day or perpetual night,—and that the middle or equatorial regions of Venus have two summers and two winters in each of her years.

354. This planet is believed to be surrounded by an atmosphere.

(3.) *The Planet* EARTH (*Tellus*), ⊕.

355. The next planet after Venus, in order from the sun, is that which we inhabit; having its orbit situated between those of Venus and Mars.

356. The mean distance of the earth from the sun is ninety-five millions of miles (95,000,000). Her excentricity is about $\frac{1}{62}$, or 0·0167836. The least distance of the earth from the sun is about ninety-three and a half millions of miles (93,500,000); the greatest distance, ninety-six and a half millions of miles (96,500,000.) The earth is in its *aphelion* on the 1st of July; in its *perihelion* on the 31st of December. The sun, therefore, appears larger on December 31st than on July 1st,—in the proportion of $32\frac{1}{2}$ to $31\frac{1}{2}$.

357. If the mean distance of the earth from the sun be 1·00000, its distance on July 1st is 1·01679; on December 31st, 0·98321.

358. The mean diameter of the earth is 7912·4 miles. The shorter or *polar* diameter is 7899·17 miles: the longer or *equatorial* diameter, 7925·64 miles. The difference between the polar and equatorial diameters is therefore 26·47 miles; or 1-299th of the longer.—The equator, or circumference of the earth at the widest part, is 24,899 miles in length,*—about 25,000 miles. A degree of longitude at the equator is 365,144 feet, or 69 British miles and 824 feet.

359. The earth's surface is marked by lines in the same manner as the sphere of the heavens.—See PARALLELS, MERIDIANS, LATITUDE, LONGITUDE, in the section on Astronomical Terms.

360. From the spheroidal form of the earth, the degrees of latitude are not all of the same magnitude, increasing from the equator towards either pole. The following table shows the length at every 30° of latitude:—

* The circumference of a circle is obtained by multiplying its diameter by 3·14159.

Latitude.	Length of degree in English feet.
0 (Equator)	362,734
30 —	363,641
60 —	365,454
90 (Poles)	366,361

Degrees of longitude of course gradually diminish from their greatest at the equator to nothing at the poles. The following table represents the length of a degree of longitude at every 20° latitude:—

Latitude.	Degree of longitude in English feet.
0 (Equator)	365,144
20° —	343,263
40° —	280,106
60° —	183,029
80° —	63,612
90° (Poles)	0

361. The earth turns upon her axis in 23 hours, 56 minutes, 4·09 seconds. This is a true or SIDEREAL DAY; termed sidereal, from *sidus*, a star; as this day is reckoned from the time of *any star* being on the meridian of a place till it returns to the same meridian again.

362. A celestial object is said to be "on the meridian of a place," when the plane of its terrestrial meridian, on being produced, would pass through the object (see Par. 201). And the coming of the object on the meridian is called "its appulse to the meridian."

363. The equatorial parts of the earth's circumference revolve at the rate of 17·3 miles per minute, or 1038 miles an hour.

364. The interval between two successive appulses of the *sun* to the meridian of a place is termed a SOLAR DAY:—that is, the time from the sun being on the meridian of a place till the earth's rotation brings it round again to the sun.

365. The solar day, for reasons stated under "Divisions of time," is longer than the sidereal day, and is not always of the same length.—The length of the mean solar day is 24 hours.

366. The earth completes her revolution round the

sun in 365 days, 5 hours, 48 minutes, 49·7 seconds; which period is termed a *tropical year*. The earth moves in her orbit at the mean rate of 18½ miles in a second, or 1110 miles every minute.

367. The *sidereal year* (see precession of the Equinoxes) is longer than the tropical year by 20 minutes 19·9 seconds; being 365 days, 6 hours, 9 minutes, 9·6 seconds.

368. The mean diameter of the sun, as seen from the earth, is about half a degree, or thirty-two minutes (32′). Its apparent diameter on the first of July, when furthest from us, is 31′ 31″—on the 31st December, when nearest to us, 32′ 35″·6.

369. That is, supposing a great circle of the heavens to be divided into 360 equal parts, the sun's diameter would be equal in length to one-half of one of these parts or degrees.

370. The mean daily motion of the earth is 59′ 8″·33; motion on 31st December 1° 1′ 9″·9; on July 1st 57′ 11″·5. The mean velocity being 1·00000, the velocity on 31st December is 1·03386; on July 1st, 0·96614 (280-1).

371. The axis of the earth is considerably inclined to the plane of its orbit. It makes an angle of 66° 31′ 20″ with the ecliptic, thus leaning 23° 28′ 40″ from the perpendicular to the orbit. Hence arise the changes in the seasons and in the length of the day.—See Seasons.

372. Hence, her *tropics*, representing the furthest north and south parallels to which the sun is vertical, are 23° 28′ 40″ from her equator; and her *arctic circles*, the parallels within which the sun occasionally never sets, or is never seen, are 23° 28′ 40″ from her poles.

373. The extent of the inclination may be seen in Fig. 10, page 25. Let the line *a o* represent the ecliptic; then N S will show the direction of the axis, forming an angle of 23° 28′ 40″ with Z *n*, the perpendicular—or, an angle of 66° 31′ 20″ with *a o*.

374. The axis of the earth preserves the same direction during the whole of its revolution round the sun; being, in any situation, parallel to its position in any other situation.

375. As the earth's axis is always parallel to itself, and the greatest distance of any two positions of the earth

(from its aphelion to its perihelion) shrinks to a point in comparison with the distance to the fixed stars, the earth's axis always points to the same place in the starry heavens, close to the north pole-star. This may readily be ascertained by observing the position of our pole-star. If this star be watched, at whatever period of the year, or at any time of the night, and its situation ascertained in reference to any fixed object, as a pillar or corner of a house, it will be always found in the same relative position to that object.

376. The mean density (see note, page 67) of the earth is about 5, compared to that of water as 1. The density of the parts at the surface is only 2·5.

377. The force of gravity at the earth's equator is diminished about 1-289th by centrifugal force: from this cause alone therefore, a body will weigh 1-289th less than at the poles. From the spheroidal form of the earth, the force of gravity is 1-590th less at the equator than at the poles.—The total difference in the force of gravity at the poles and equator, is equal to the sum of these quantities, or 1-194th, for $\frac{1}{289}$ and $\frac{1}{590}$ make $\frac{1}{194}$. Accordingly, a body which weighs any given quantity at the poles, as indicated by a spring balance, must be increased in weight by 1-194th part, to produce the same effect on the spring at the equator.*

378. The temperature of the earth at the surface is regulated entirely by the solar influence;—see Climate and Seasons. But this influence does not extend above 100 feet below the surface, owing to the slowness with which heat travels through the matter of which the crust of the earth is composed.

379. The earth is found, in every part where it has yet been tried, to become sensibly and regularly warmer in proportion as the distance below the surface is greater; the temperature increasing about one degree Fahrenheit for every descent of 45 or 50 feet. From this it is

* The increase of the force of gravity from the equator towards either pole is in the proportion of the *square of the sine of the latitude*.

inferred that the parts in the interior are very hot, and perhaps so much so as to be kept in the fused condition, and be fluid.

The Moon (*Luna*), ☽.

380. The moon is a satellite or secondary planet to the earth, round which it revolves, and with which it is carried annually round the sun.

381. The mean distance of the moon from the earth is about two hundred and thirty-seven thousand miles (237,000). Her distance from the earth does not vary much. Her excentricity is about 1-20th of her mean distance from the earth, or about 12,000 miles.

382. The earth will appear at the moon about 13 times larger than the moon does to the earth; and supply that satellite with a proportionately more brilliant light than she affords to us.

383. The diameter of the moon is 2160 miles, a little more than 1-4th of that of the earth. The bulk of the moon is about $\frac{1}{49}$th of that of our earth, or as ·0204 to 1.

384. The moon performs her revolution round the earth in 29 days, 12 hours, 44 minutes; and appears to turn upon her axis in the same time. This is the period from one new moon to the next,—from the time of the moon being in conjunction with the sun till she comes to the same position again,—and it is termed a *synodical* month, or her *synodical* revolution.

385. The moon moves in her orbit at the rate of 2-3ds of a mile each second, 37·9 miles in a minute, or 2277 miles per hour.

386. From the period of the moon's rotation on her axis being the same as that of her revolution round the earth, she always presents the same side to the earth. And that side is never totally dark, having one fortnight of sun-light, and being illuminated by the earth the other fortnight. The other side has alternately a fortnight of sun-light and a fortnight of darkness.

387. Viewed, not with respect to the sun, but to the

stars, the moon is found to return to the same star in 27 days, 7 hours, 43 minutes. This is termed a *sidereal* or *periodical month;* and is the true period of the moon's revolution round the earth and on her axis.

388. The plane of the moon's orbit forms an angle of 5° 8′ 47·9″ with the plane of the earth's orbit; so that the two orbits are not very far from being in the same plane.

389. The moon's axis scarcely leans towards the earth's orbit, forming an angle of 88° 30′ with the plane of the ecliptic,—or leaning only 1° 30′ to the ecliptic.—Being so nearly perpendicular to the plane of the ecliptic—the path in which the moon moves round the sun—the moon can have little or no change in the seasons, or in the length of the day.

In subsequent sections, the moon, and leading phenomena in which she is concerned, will be more fully described.

(4.) *The Planet* MARS, ♂.

390. MARS is the next planet beyond the earth, the orbit of this planet lying between those of the earth and Vesta.—It is the first of the superior planets (226).

391. The mean distance of Mars from the sun is one hundred and forty-four millions five hundred thousand miles (144,500,000). His distance from the sun varies considerably; his excentricity is a little less than 1-10th of his mean distance from that luminary.

392. The diameter of the sun, seen from Mars, is to his apparent diameter at the earth, as 21 to 32, nearly as 2 to 3. The sun's influence at Mars is a little less than one-half of what it is at the earth—correctly, as $95^2 : 144^2$, or nearly as 9 : 20.

393. The diameter of Mars is about 4100 miles—a little more than one-half of the earth's diameter.

394. Mars rotates on his axis in 24 hours, 40 minutes ($24^{h.}\ 39^{m.}\ 21^{s.}$).

395. Mars performs his revolution round the sun in 686 days, 23 hours; moving in his orbit at the rate of 15 miles in a second, or 900 miles per minute.

396. The planes of the orbits of Mars and the earth are nearly coincident, the angle between them being one of only 1° 51′ 3″.—See Fig. 12, page 39.

397. The axis of Mars is considerably inclined to the plane of his orbit, forming with it an angle of 61° 35′, about 2-3ds of a right angle; leaning from the perpendicular about 28° 25′. Therefore, there must be a considerable variety in the seasons at Mars;—more proportionally than at the earth, though less than at Venus.

398. This planet is frequently pretty near the earth, and therefore, though small, appears tolerably large and bright; but much less so than Venus or Jupiter. Mars shines with a distinctly red light, but is dull and dusky looking.

399. Owing to the great length of the diameter of Mars' orbit, there is a very great difference between his distance from us in opposition and in conjunction; so much so, that while his diameter appears equal to 18″ in opposition, it is only 4″ in conjunction.

400. When viewed through a telescope, Mars is found to exhibit PHASES; his apparent magnitude varying according to the amount of the illuminated part which is turned towards us. This shows that Mars is not self-luminous, but shines by reflecting the sun's light. Also, the regions about the poles of Mars are observed to be more bright than the other parts. This, it is conjectured, is caused by an accumulation of snow and ice around his poles, similar to what prevails in the polar regions of the earth. Snow and ice reflect light brilliantly; and, if his poles are covered by these, as ours are, this certainly would give rise to a brilliancy in the appearance of these regions. The conjecture that this whiteness is caused by snow or ice is confirmed by the circumstance that it disappears after long exposure to the sun, and is largest and brightest after the winter of the planet.

401. Mars is believed to possess a considerable atmosphere (to the density of which, his ruddy colour has been ascribed); and his surface is variegated in a manner

which has been attributed to parts of it being covered with water.

402. The presence of an atmosphere around Mars is conjectured from the appearance presented when he approaches any star. The star is dimmed, changed in colour, and disappears before it reaches the body of the planet.

(5—8.) *Asteroids.*

403. The asteroids are four small recently discovered planets, situated between the orbits of Mars and Jupiter, and termed VESTA, JUNO, CERES, PALLAS. They are sometimes called *telescopic*, as they are not visible to the naked eye, but can only be seen by the aid of the telescope.

404. Ceres was discovered by PIAZZI, on the 1st January 1801; Pallas by OLBERS, on the 28th March 1802; Juno, by HARDING, on the 1st September 1804; Vesta by OLBERS, on the 29th March 1807.—Their signs are Vesta ⚶, Juno ⚵, Ceres ⚳, Pallas ⚴.

405. The following are the distances, in millions of miles, and periods of revolution round the sun, of these small planets:—Vesta, 223; 1335·7 days:—Juno, 252; 1592 days:—Ceres, 261; 1681 days:—Pallas, 262; 1686 days.

406. The diameters of these planets have not been correctly ascertained. Vesta's diameter has been stated at about 1891 miles; that of Juno, about 1400 miles; Ceres, so small as 140 miles; and Pallas, 1950.

407. Their excentricities are considerable; and they are remarkable for the great angle which the planes of their orbits form with the ecliptic, the inclinations being as follows:—Vesta, 7° 8′ 9″; Juno, 13° 3′ 28″; Ceres, 10° 37′; Pallas, 34° 37′. See Fig. 12, page 39, in which their great departure from the plane of the ecliptic is shown: the lines furthest to the right show the inclinations of the orbits of these planets. From their orbits being so much out of the plane of the ecliptic, they are seldom seen in the zodiac, being generally above or below it; while all the other planets constantly appear in that

zone of the heavens. Hence, these four planets are sometimes termed *ultra-zodiacal, i.e.* out of, or beyond the zodiac.

408. The asteroids present several peculiarities, in which they differ considerably from the other planets.

409. (1.) They are extremely small, while, generally speaking, the planets rather increase in size as they are more distant from the sun.

410. (2.) They are *all at nearly the same distance from the sun,*—viz. varying only from 223 to 262 millions of miles; or, the nearest is only about 1-5th (2-11ths) of its distance nearer than the most remote; whereas, a very different law prevails with respect to the other planets,—the distance between two planets increases in a very high proportion as they are further from the sun: as is seen as follows:—Mercury, 37; Venus, 69; Earth, 95; Mars, 144.

411. The following singular relation has been observed regarding the distances of the planets; and it led to the conjecture of the existence of another planet between Mars and Jupiter, before the discovery of the asteroids.

If the numbers, 0, 3, 6, 12, 24, 48, 96, 192, be taken, and the number 4 added to each, the sum will express the proportionate distances of the planets in order from the sun:

0	+	4	=	4,	Distance of	Mercury.
3	+	4	=	7,	...	Venus.
6	+	4	=	10,	...	Earth.
12	+	4	=	16,	...	Mars.
24	+	4	=	28,	...	
48	+	4	=	52,	...	Jupiter.
96	+	4	=	100,	...	Saturn.
			added afterwards,			
192	+	4	=	196,	...	Uranus.

A void being observed between the numbers 16 and 52, Professor Bode conjectured that a planet filling up the vacant number might exist, which was confirmed by the discovery of the asteroids, in the situation in the solar system indicated by the vacant place.

412. (3.) Their orbits are very far out of the plane of the ecliptic, whereas the orbits of the other planets are nearly coincident with that plane. The orbits of Venus, Mars, Jupiter, Saturn, Uranus, form angles with the plane of the ecliptic of from 3° 23′ to 0° 46′, and Mercury of 7°;—but the angles which the asteroids form with that plane are 7°, 10°, 13°, and 34°.—See Fig. 12, page 39.

413. These peculiarities have led to the singular conjecture, that these four small planets originally formed *one planet;* that that planet has been ruptured by some great convulsion, which has divided the *one* into *four*, and thrown the fragments out of the former orbit (which perhaps was nearly coincident with the plane of the ecliptic) into orbits deviating considerably from the general order.

(9.) *The Planet* JUPITER, ♃.

414. Jupiter is the next planet beyond the asteroids, his orbit lying between those of Pallas and Saturn. He is the largest of the planets, and, though so remote from the earth, owing to his great magnitude, often appears as bright and large as Venus.

415. The mean distance of Jupiter from the sun is about four hundred and ninety-three millions of miles (493,000,000). His distance from the sun does not vary much, his excentricity being less than 1-20th of his mean distance.

416. The sun's diameter as seen from Jupiter is only 1-5th of its apparent magnitude at the earth,—correctly, as 6 to 32. The relative proportion of the sun's influence at Jupiter and at the earth is as 1 to 26 (as $95^2 : 493^2$).

417. The diameter of Jupiter is upwards of eighty-six thousand miles (86,000), nearly eleven times that of the earth. This is the equatorial diameter.

418. The polar or shorter diameter of Jupiter is about 1-14th, or 6000 miles, less than the equatorial diameter; or, as 100 to 107. The great difference between the polar and equatorial diameters of this planet is attri-

buted to the very great centrifugal force generated by his rapid rotation on his axis.

419. Jupiter turns on his axis in a little less than 10 hours,—correctly, 9 hours 55 minutes. His equatorial parts, therefore, revolve at the amazing rate of 7·5 miles in a second, or 453 miles per minute.

420. Jupiter completes his revolution round the sun in 4332½ days, nearly 12 of our years (more correctly, 11 years 314 days):—moving in his orbit at the rate of 8 miles in a second, 480 miles in a minute, or 28,000 miles per hour.

421. The planes of the orbits of Jupiter and the earth are nearly coincident, the angle between them being only 1° 18′ 51″.

422. The axis of Jupiter does not lean towards the plane of his orbit, being perpendicular to that plane. From this, Jupiter can have little or no variety in his seasons, and little or no change in the length of the day. This planet, therefore, will have a perpetual winter around his poles, and continual summer in his equatorial regions; and the weather comparatively uniform.

423. When viewed through a telescope, Jupiter appears of a distinctly oval shape, from the extreme polar flattening.

424. Also, there are observed on his surface, a number of zones, striae, or BELTS, chiefly about, and in a direction parallel to his equator, and of a darker hue than the other parts. They vary considerably in form and position, and are therefore considered to be caused by changes in the atmosphere of the planet: perhaps by uniform currents in certain directions, analogous to the trade-winds on the surface of our own planet.—See Section V., on the Trade-winds.

Satellites of Jupiter.

425. This planet is attended by four satellites or moons. These cannot be seen by the naked eye, and hence they were not known till after the invention of the telescope. In 1610, within a very short time after

the discovery of this powerful instrument of astronomical observation, the satellites of Jupiter were discovered by GALILEO.

426. They were called at first Medicea Sidera, or Medicean stars, in honour of the house of MEDICI.

427. The distance from Jupiter of his nearest satellite is 258,000 miles; its diameter is 2508 miles; and it revolves round its primary planet in 1 day, 18 hours, 28 minutes.

428. The distance from the planet of the next satellite is 412,000 miles; its diameter is 2068 miles; and it completes its revolution round Jupiter in 3 days, 13 hours, 14 minutes.

429. Jupiter's third satellite is at a distance of 577,000 miles; its diameter is 3377 miles; and it revolves round Jupiter in 7 days, 3 hours, and 43 minutes.

430. The fourth and most remote of Jupiter's satellites is distant from him 1,161,000 miles;—its diameter is 2890 miles;—and it occupies 16 days, 16 hours, 32 minutes in its revolution round Jupiter.

431. The satellites of this planet are rather larger in general than our moon.

432. Jupiter's satellites revolve round him *from west to east*, as the moon does round the earth, and the planets round the sun.

433. The periods of rotation on their axes are the same as their periods of revolution round their primary planet;—obeying, in this respect, the same law as our satellite, the moon.

434. When the body of Jupiter interposes between the sun and any of his satellites, that satellite will disappear from our view, *or be eclipsed.*

435. The eclipses of Jupiter's satellites are phenomena of considerable importance in practical astronomy. They afforded the most accurate method of determining the longitude of places on the earth's surface; this mode, however, is now superseded in a great measure by lunar observations.

436. The eclipses of the satellites of Jupiter have been the means of leading to the great discovery that *the passage of light from one point to another is not instantaneous, but requires a certain time;* and they have also

enabled the rate of its motion to be calculated. This great discovery was made by ROEMER, a Danish astronomer, in the year 1675.

437. Owing to the great distance of Jupiter from the sun, there must be a considerable difference between his distance from the earth when he is nearest us, or in opposition, and his distance when he is furthest from us, or in conjunction.* Now, ROEMER found that the eclipses of Jupiter's satellites took place *sooner* than might be expected when he was nearest the earth; and *later* than might be expected when he was most distant from the earth, the total difference amounting to 16 minutes, 26 seconds. This he explained by the supposition that light does not pass instantaneously from one point to another, but requires time for its transmission, and that therefore the rays which intimate to us the eclipse of one of Jupiter's satellites, must be longer in coming to us when he is remote than when near, an eclipse in the former case appearing *later* than in the latter. That the variation from the computed time of an eclipse of a satellite of Jupiter is owing to light occupying time in its transmission, was afterwards confirmed by Bradley's great discovery of the Aberration of Light.

438. Thus, we do not see distant phenomena at the actual moment of their occurrence, but some time after, sooner or later according to the distance.

439. The velocity of light, as computed from the above data, is 192,000 miles in a second, or about 11,520,000 miles in a minute.

(10.) *The Planet* SATURN, ♄.

440. This is the most remote of the planets but one. Its orbit lies between those of Jupiter and Uranus. Saturn appears between Mars and Jupiter in magnitude, and shines with a rather dull light.

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* In opposition, the distance of Jupiter from the earth will be the *difference* between the radii of the two orbits, 490 — 95;—in conjunction, the *sum* of the two radii, or 490+95. The difference between these two amounts to 190 millions miles, or the whole diameter of the earth's orbit.

441. The mean distance of Saturn from the sun is nine hundred and four millions of miles (904,000,000). His excentricity is more than 1-20th of his mean distance from the sun.

442. At Saturn, the sun will present a diameter about 1-10th of that seen at the earth. The proportion of the sun's influence which reaches Saturn is about 1-90th of that enjoyed at the earth—as 95^2 to 904^2.

443. The equatorial diameter of Saturn is about 79,000 miles. The polar diameter of this planet is stated to be about 1-11th less than the equatorial. Having a very rapid rotation on its axis, it is to be expected that Saturn, like Jupiter, will be very much flattened at his poles.

444. Saturn rotates on his axis in 10 hours 16 minutes.

445. Saturn completes his revolution round the sun in 10,759 days, or about 29½ years;—moving in his orbit at the rate of about 6 miles in a second, or 360 miles in a minute.

446. The planes of the earth's orbit and of Saturn's are nearly coincident, the angle between them being only 2° 29′ 35″.

447. The axis of Saturn is not at right angles to the plane of his orbit; but makes an angle of about 62° with that plane, leaning 28° from the perpendicular. There must be therefore considerable variety in the seasons at Saturn.

448. When viewed through a telescope, stripes or belts are observed on Saturn's surface, resembling those seen on Jupiter, but more faint.

449. The most remarkable feature observed about this planet is, an enormous RING by which it is surrounded. This very singular appendage (see the representation of Saturn in Fig. 12, page 39) seems to be of solid matter; for it throws a shadow on the body of the planet; and is thin, flattish, broad, and opaque. It is at a considerable distance from the body of the planet; and consists of TWO RINGS, one within the other, and both in the same plane, which is nearly the same as the plane of the

planet's equator. The rings rotate, *in their own plane*, in about 10 hours and 29 minutes. Thus, the axis of rotation of the planet and its ring must be nearly the same.

450. The inner margin of the inner ring is about 19,000 miles from the body of the planet; and the breadth of this ring is 17,000 miles.—The distance between the two rings is about 1790 miles.—The breadth of the external ring is upwards of 10,000 miles.—The thickness of the rings has been estimated at about 100 miles.

451. The use of this stupendous object is probably the same as that of the satellites—to reflect light upon the planet,—an important object in the case of planets so remote from the sun.

452. GALILEO, in 1610-12, observed several remarkable peculiarities in the appearance of Saturn. In 1656, HUYGENS, provided with better telescopes, discovered these peculiarities to be caused by a ring surrounding the planet. Towards the close of last century, about 1790, the ring was discovered by Sir William Herschel to be double, consisting of one ring within another, both in the same plane.

Satellites of Saturn.

453. This planet is accompanied by no less than seven satellites. The six which are nearest to the planet have their orbits nearly in the same plane as the ring. The satellites of Saturn are supposed to revolve on their axes in the same periods in which they complete their revolutions round the planet. This has been ascertained of the seventh.

454. The seventh is the largest, and is believed to be of greater magnitude than the planet Mercury.

455. The *first* satellite is at a distance of about 130,000 miles from Saturn, and revolves round it in 22 hours 38 minutes:—the *second* is about 170,000 miles from the planet, and completes its revolution in 1 day, 8 hours, 53 minutes:—the *third* is about 205,000 miles from Saturn, and its period is 1 day, 21 hours, 18 minutes:—the distance of the *fourth* is about 268,000 miles; its period 2

days, 17 hours, 45 minutes :—the *fifth* is about 375,000 miles from Saturn, and revolves round him in 4 days, 12 hours, 25 minutes :—the *sixth* is about 870,000 miles from the planet, and revolves round him in 15 days, 22 hours, 41 minutes :—the distance of the *seventh* is about 260,000 miles; and its period, 79 days, 7 hours, 55 minutes.

456. The satellites of Saturn were discovered by Huygens, Cassini, and Herschel;—the fourth by Huygens in 1655—four others by Cassini in 1671 and subsequent years: the first and second by Dr Herschel in 1789.

(11.) *The Planet* Uranus, ♅.

457. Of the planets at present known, this is the most remote from the sun. Though of considerable magnitude, it is, from its great distance, rarely and with difficulty seen by the naked eye.

458. This planet was discovered by the celebrated astronomer Sir William Herschel, on the 13th of March 1781.

459. It was called by him "Georgium Sidus," in honour of George III., and by some astronomers, "Herschel," in honour of the discoverer. The name Uranus, however, from one of the characters in the ancient mythology, is preferred, as being more in harmony with the appellations of the other planets.

460. The mean distance of Uranus from the sun is eighteen hundred and nineteen millions of miles (1,819,000,000), a little more than 19 times the distance of the earth from the sun.—The distance of Uranus from the sun does not vary much, his excentricity being less than 1-20th of his mean distance.

461. The sun's diameter appears at Uranus of 1-19th the apparent magnitude at the earth, as $1\frac{2}{3}$ to 32 :—and the proportion of the sun's influence enjoyed by this planet is only 1-366th of that experienced at the earth: as 95^2 to 1819^2.

462. The diameter of this planet is nearly 35,000 miles.

463. Uranus completes his revolution round the sun

in 30,686 days, about 84 years;—moving in his orbit at the rate of 4 miles in a second, or 240 miles every minute.

464. The plane of the orbit of Uranus is more nearly coincident with that of the ecliptic, than in the case of any other planet, the angle between them being only 0° 46′ 26″.

Satellites of Uranus.

465. This planet is attended by six satellites. They were first observed by the discoverer of the planet itself, Sir William Herschel, in the years 1787 and 1798.

466. The nearest is about 227,000 miles from the planet, and revolves round him in 5 days, 21 hours, 25 minutes. The most *remote* is about 1,600,000 miles from Uranus, and completes his revolution round him in 107 days, 16 hours, 40 minutes.

467. These satellites present some remarkable peculiarities and departures from the usual order in the solar system. The planes of their orbits are nearly perpendicular to the plane of Uranus' orbit, forming an angle of 78° 58′ with the plane of the ecliptic (464); and they do not move in the same direction which prevails every where else in the solar system, viz. from *west* to *east;* but in a retrograde direction, *i. e.* from *east* to *west.*

III.—COMETS.

468. The comets are those stars which appear at times in various parts of the heavens, describing an apparently irregular course when compared with the planets; approaching very near to the sun, and again receding to a great distance from him and disappearing.

469. Comets appear under very various aspects. Usually, there is a brilliant luminous point called the *nucleus;* the *coma* or hair is the more diffuse light surrounding the nucleus; these two constitute the *head;* and there is

often present, though not always, a long luminous appendage, called a *tail.* The tail is turned in a direction *from* the sun: and frequently is bifurcated, that is, divides into two branches, sometimes into more. Occasionally it is bent into a gentle curve.

470. The comets are considered to be masses of vaporous matter, or solid nuclei surrounded by much aerial matter, revolving round the sun in very elongated ellipses, so that at one time they are very near the earth and sun, and at another time very remote from these orbs.—See Fig. 11, page 37, in which the entire orbit of one comet (that of Biela) and part of the orbit of another, are represented.

471. The tails of the comets vary considerably in magnitude. The tail is often scarcely perceptible at first, enlarges as the comet approaches to the sun, is most developed just after it has passed its perihelion; and gradually diminishes as the distance from the sun increases, and the influence of that body lessens. The tails of some comets have been estimated at upwards of 100 millions of miles in length. Some have had the extremities of their tails in the zenith, while they themselves were in the horizon. From the above phenomena, it has been conjectured that the tails of comets are formed of matter ejected from its body by the influence of the sun's heat.

472. The comets revolve in extremely excentric* orbits. The great comet of 1680 was calculated to have approached within about 150,000 miles of the sun,—about one-sixth of his diameter.

473. The periods in which several of the comets revolve round the sun have been computed, and the correctness of the calculation proved by the return of the comet several times.

474. A very bright comet was recorded to have been

* Excentric, out of the centre—the focus being far from the centre of the ellipse. This elongates the major axis (51), and causes the aphelion and perihelion to be at very unequal distances from the sun.—See Par. 186-7-8.

seen in the years 1531 and 1607. In 1682, a comet appeared, which was observed by the celebrated astronomer HALLEY, and calculated by him to be the same which had been seen in 1531 and 1607. He accordingly predicted its return in about 1758, computing it to have a period of between seventy-five and seventy-six years. It did appear, to the great delight of the astronomical world, in 1759, nearly about the assigned period; its delay being caused, as predicted by HALLEY and correctly calculated by CLAIRAUT, by the action of Jupiter and Saturn upon it. This comet has again, in 1835, returned at the calculated time. In 1682, the tail of this comet stretched over a space of 30°. It is conjectured also to be the same comet which appeared in 1305 and 1456.

475. The comet of BIELA performs its revolution in the short period of $6\frac{3}{4}$ years. It does not pass much beyond the orbit of Jupiter. The orbit of this comet is represented in Fig. 11, page 37—the dotted ellipse, of which the outline is complete. It is not visible to the naked eye.

476. The comet of ENCKE has a still shorter period, $3\frac{1}{3}$ years, or 1207 days.

477. The latter, the comet of ENCKE, has led to some singular speculations regarding the existence of a fluid, called *the ether*, supposed to be spread out through space. Its period of revolution round the sun is found to be diminishing. This is attributed to a resistance opposed to its progress by some material fluid through which it passes, which weakens its centrifugal force, gives the sun's attractive force larger proportionate power, enables that body to draw it into a smaller orbit, in which it moves more rapidly, and therefore runs through its course in a shorter time.

478. Some comets have been so exceedingly bright, as to be visible in daylight. This was the case with the great comets of 1402 and 1532.

479. The number of comets which circulate in the solar system is supposed to be very great,—perhaps thousands. Hundreds have been recorded; and it is

believed that the proportion of comets which are visible to us must be very considerably under the number which really exist.

480. Comets appear in all parts of the heavens, move in all directions, and with very different degrees of velocity. They are not, like the planets, confined to the zodiacal belt.

481. Comets are considered to be mostly, if not entirely, in the aerial state, for the following reasons. The stars, even those of very small magnitude, can be seen through the substance of many of the comets. They have been found to cause no sensible derangement in the motions of some of the satellites of Jupiter near to which they have passed; while they themselves have been considerably influenced and diverted from their course; indications that their mass (263) is small, and therefore, as their bulk is considerable, that they are most probably in the aerial state. Also, they present no *phases*, which seems to show that light is reflected from every part of the comet, and hence, that the sun's light penetrates their substance, which also indicates an aerial state.

482. In ancient times, comets were supposed to resemble planets, and like them, to go through certain revolutions in regular periods. But from the commencement of the Christian era to the time of TYCHO BRAHE, they were generally regarded by astronomers merely as METEORS, existing in the atmosphere. He found that their distances were beyond that of the moon; and the idea that comets are at considerable distances, and revolve round the sun in regular periods, was confirmed by KEPLER, HEVELIUS, DORFEL, NEWTON, and HALLEY.

SECTION IV.

DAY AND NIGHT—CLIMATE—SEASONS.

1. *Day and Night.*

483. The constant and regular alternation of a period of light, termed DAY, and a period of darkness, called NIGHT, is caused by the earth's rotation on its axis.

484. The word *day*, as used in this section, signifies the period of light, that is, the period during which the sun is *above* the horizon of a place (197-8); *night*, the period when the sun is *below* the horizon of the place, and darkness prevails.

485. The change from night to day and day to night takes place in the following manner:—The sun enlightens only that half of the earth's surface which is turned towards him, while the other half is in darkness;—and, as the earth, by its rotation on its axis, successively presents every part of its surface to, and turns it from, the sun,* each part must have alternately light and darkness, or day and night.

Proportions of Day and Night at different Places.

486. At the equator, the day and the night are of equal length during the whole of the year;—and there is a day and a night during each rotation of the earth on its axis, *i. e.* in every 24 hours;—the day and the night being 12 hours long each.

487. At the POLES, the day and the night are of equal length during the whole of the year;—but there is only *one day and one night* during the whole of the year, each being about six months in duration.

488. At other parts of the earth's surface the duration of day and night is different at different places, and at the

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* Not that every part of the earth's surface is turned towards the sun during *each rotation;* for this is not the case—but, during the year, every part of the earth's surface is at some period turned towards the sun.

same place at different times. The parts north of the equator (*northern hemisphere*) and those south of the equator (*southern hemisphere*) are always in exactly opposite conditions with respect to day and night. At corresponding latitudes, north and south (that is, at latitudes equally distant from the equator), one has day when the other has night, the one's day is equal to the other's night, the one has *short day* and *long night*, when the other has *long day* and *short night*.

489. At two periods in each year, there is equal day and night over all the world;—and a day and a night during each rotation of the earth. These two times are termed EQUINOXES (211). They are, March 20, the spring or *vernal equinox*, and September 22, the *autumnal equinox*.

490. From the equator to latitude 66° 32′ north, and to the same distance south, the day and night are unequal at different places, and at the same place at different times, excepting at the EQUINOXES:—and there is always a day and a night during each rotation of the earth on its axis. These latitudes, it must be observed, are 23° 28′ distant from the poles.

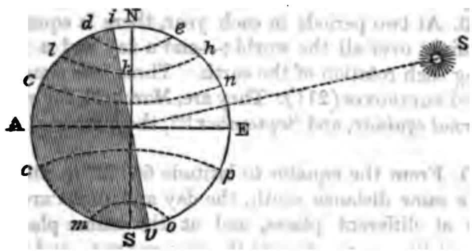
491. From latitude 66° 32′, north and south, to each pole, the day (484) or period of sunshine, during part of the year, *continues for several rotations of the earth on its axis*;* the time the sun remains above the horizon varies from nothing to six months; the day is extremely long when there first comes to be a day and a night during each rotation; and the proportions gradually change till there is *continual night* during several rotations—and so on.

492. The regions on each side of the equator, for 23° 28′ north and south of it, are called the TORRID ZONE;—or *tropical regions*, lying between the tropics of Cancer and Capricorn. The regions between the tropics and the arctic circles, *i.e.* to lat. 66° 32′, are called TEMPERATE; and the districts around each pole for 23° 28′ from

* That is, for several *days of 24 hours*, the sun never sets.

it, *i. e.* within the polar circles, are the POLAR or FROZEN regions. Thus, in Fig. 25, below, if *d e*, *m o*, be the polar circles, *c n* and *c p* the tropics of Cancer and Capricorn, then the regions north of *d e* and south of *m o* are the *frozen regions;* those between *d e* and *c n*, and between *m o* and *c p* the temperate regions;—and the parts between *c n* and *c p* the torrid zone.

Fig. 25.



Manner in which these Differences occur.

493. The line between the dark part and the enlightened part of the earth's surface is called the TERMINATOR. It may be called the *boundary line* between night and day. It forms a great circle (54), all round the globe, its plane passing through the centre of the earth: in Fig. 25, above, the line *i v*, bordering the shaded part, is the terminator. The sun is always perpendicular to the plane of the terminator.

494. The terminator is on each spot of the earth's surface at two periods during each rotation; first, when it is *sunrise*, and, again, when it is *sunset* at that place; and the sun is on the meridian of a place, or there is midday, when the place is equally distant on both sides from the terminator; also, the length of the day and the night at different places depends upon the proportionate lengths of time which are spent on each side of the terminator.

495. The sun is always perpendicular to some part of the earth's surface, *i. e.* is always in the zenith at some

place: and the terminator will be 90° distant, all round, from the spot on which he is vertical at any time.

496. During one rotation of the earth on its axis (disregarding the earth's motion in its orbit during the time of one rotation), the parts successively brought round to be perpendicularly under the sun will be *those in the same parallel of latitude.* Thus, if in Fig. 26, page 99, A N E S be the earth, N S the earth's axis, S at the side the sun, and *n* the point at which the sun is vertical, the line *d o*, supposed to represent the terminator, will evidently be 90° distant from *n*. And as N S is the axis, about which the earth turns, the points that will be successively brought into the position of *n* by the rotation, will be those on the parallel C *n*; and the sun is then said to be vertical or perpendicular to that parallel: for, although he is perpendicular only to one point of it at a time, viz. where it is mid-day, he is during the whole rotation perpendicular to some part of it.

Long Day, &c. in the Northern Hemisphere.

497. Now the sun on the 21st of June is perpendicular to the north tropic (tropic of Cancer), which is only 66° 32′ from the north pole: accordingly the terminator will then be 90° from that parallel, or 23° 28′ *beyond the north pole:* that is, reaching to the arctic circle. In revolving, therefore, that pole and all within the arctic circle (the parts around it for a distance of 23° 28′* south) will have continual day; for they will never cross the terminator in their revolution. The sun will not set there, but describe a circle near the horizon varying slightly in its elevation. The parts further south, from lat. 66° 32′ to the equator, will describe *more than half of their daily circle on the enlightened side of the terminator*, and have longer day than night. And the proportion without the terminator will diminish as the place is further south, till, at the equator, an equal

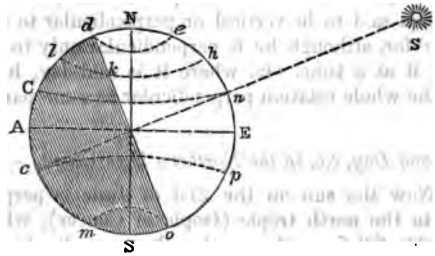
* 66° 32′+23° 28′ = 90°.

portion of the time of rotation will be spent on each side of the terminator, and the day and the night will be equal.

498. The tropic of Cancer, latitude 23° 28′, is the furthest north parallel to which the sun becomes perpendicular. At places further north, he never reaches the zenith,—never appears perpendicular—and his elevation is less as the place is more north.

499. This will be better understood by referring to the adjoining figure, which illustrates the relation of the dark and illumined parts when the sun is on the tropic of Cancer.

Fig. 26.



Let A N E S represent the earth, N the north pole, S the south pole, N S the axis about which it turns; S, at the right, the sun, *d* A *o* the part of the earth not receiving the sun's light, *d o* the line of the terminator. Let *d e* be the arctic circle, 23° 28′ from the north pole; C *n*, the tropic of Cancer, 23° 28′ from the equator. It will be seen from the position of the sun that the north pole is turned towards it, and the south pole from it. Any point, in revolving, will take twelve hours in passing from one side of N S to the other, as from *e* to *d*, or *n* to C, and twelve hours in returning again: and the middle of each twelve hours will be where the point crosses N S. Now, the planet revolving about N S, it will be at once evident that any point north of the dotted circle

d e (the arctic circle), will never be out of the sun's rays, and therefore have constant day; that any point from *d e* to A E the equator, will be more than half the period of rotation without the terminator; that it will be a less proportion of its course without the terminator, as it is further south from *d e*; that any point in A E will spend half its course within, and half without the terminator, as that circle cuts A E, the circle in which such a point revolves, exactly in the middle.

500. The point *h*, for instance, revolving in 12 hours from *h* to *l*, will have *h* for its mid-day or noon, when nearest to the sun; the point *k*, where the circle *h l* cuts the terminator, for sunset; and *l* for midnight. As the period from noon to sunset (from *h* to *k*) is longer than that from sunset to midnight (*k* to *l*), so likewise the time from sunrise to noon is longer than that from midnight to sunrise;—and the whole day of that point will be longer than its night.

Short Day in the Northern Hemisphere.

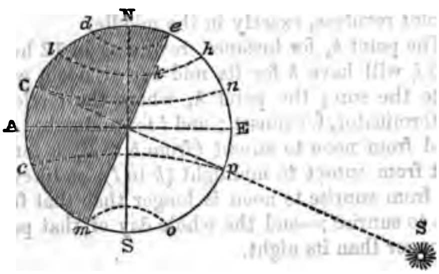
501. On the 22d of December, the sun is perpendicular to the *south tropic* (tropic of Capricorn), which is 23° 28′ *south* of the equator, or 113° 28′ (23° 28′ + 90°) from the north pole. Accordingly, the sun will then be 90° from the arctic circle, and the terminator will be 23° 28′ *on this side of the north pole.* In revolving, therefore, that pole, and all within the arctic circle (the parts around it for a distance of 23° 28′ north), will have continual night, for they will never cross the terminator, but just skirt it in their revolution. The sun will never rise there. The parts further south, from 66° 32′ to the equator, will *describe more than half their daily circle on the dark side of the terminator*, and have longer day than night. And the proportion within the terminator will diminish as the place is further south, till, at the equator, an equal portion of the time of rotation will be spent on each side of the terminator, and the day and the night will be equal.

502. The tropic of Capricorn, latitude 23° 28′ south, is

the furthest south parallel to which the sun becomes perpendicular. At places further south, he never reaches the zenith—never appears perpendicular—and appears lower as the place is further south.

503. This will be better understood by reference to the adjoining figure; which illustrates the relation of

Fig. 27.



the dark and illumined parts when the sun is on the tropic of Capricorn. The same letters indicate the same parts as in the former figure (page 99), excepting those at the terminator, which is now from *e* to *m*, completely enveloping in the shade the north pole and the regions around it for 23° 28′ south. Within the arctic circle there will be continual night. From that parallel to the equator A E, any point, in its daily rotation, will pass from mid-day to the terminator before it has gone through half of its circle, and will therefore have longer night than day. It will be enveloped in the dark half sooner after noon, and have longer night, in proportion as it is nearer to the pole. And as the terminator *e m* still cuts the equator in two equal parts, there will be equal day and night at the equator. Thus, the same point *h* is seen to pass to the point *k*, where it meets the terminator, in less than six hours, and to be more than six hours in revolving from *k* to *l*, its midnight. From midnight to sunrise will also be more than six hours; and its whole night must be greater than its day.

504. Thus, the northern hemisphere, with respect to the dark part of the earth's surface, is placed on December 22 (in Fig. 27) in exactly the same position formerly illustrated with respect to the illumined part.

State of the Southern Hemisphere.

505. As already mentioned (488), the two hemispheres are always in exactly opposite conditions in regard to day and night, except at the time of the equinoxes. This is at once seen by inspection of Figures 26 and 27. When the sun is on the north tropic (Fig. 26), and the north pole is entirely in the illumined part, the south pole is entirely in the shade. When the sun is on the south tropic (Fig. 27), the north pole is out of the reach of his rays, and the south pole is never out of them, &c. At the equinoxes, when the sun is perpendicular to the equator, and the terminator passes through both poles, each hemisphere is situated in the same position with respect to the sun's rays, and are therefore in similar conditions as to day and night.

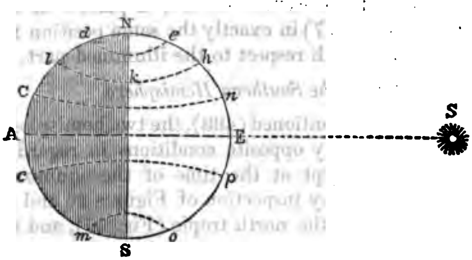
Equal Day and Night over all the Earth.

506. At the equinoxes, the sun is perpendicular to the equator, or appears in the zenith at that parallel, *and the terminator*, always 90° distant from the parallel at which the sun is vertical, *passes through both poles;* and its plane passes through the earth's axis. Then, there is equal day and night over all the earth: for every part will spend half of its rotation without and half within the terminator.

507. This is illustrated by the following figure, which exhibits the state of the world with respect to day and night when the sun is on the equator. The sun is seen perpendicular to the earth at the equator, the terminator crossing each pole 90° on each side from the point to which the sun is vertical.

508. In this figure, it is evident that each point in the illumined half, N E S, in revolving from the sun, or its noon, as *h*, to its midnight *l*, will cross the terminator

Fig. 28.



at *k*, exactly half-way between these two periods—that is, in six hours. The same will take place in passing from *l* back to *h*; and the night and day must therefore be equal on every part of the earth's surface.

509. At the poles at this period the sun will appear to move round the horizon; and, as he thus neither rises nor sets, there will be continual day there. For some time after, also, as refraction and reflection prolong the day, there will be continual day there, even though he be actually a little below the horizon.

Of the CHANGE *in the Length of the Day.*

510. The gradual change of the length of the day occurs in the following manner:—When it is said that the sun travels from or to any parallel, it is meant that he travels from being vertical to it, or to being vertical to it.

511. When the sun is vertical to the tropic of Cancer, he is at the furthest north parallel which he reaches (Fig. 26), and from that travels south from *n* to E and *p*;—by this, the terminator slowly wheels round from *d o* (Fig. 26) to N S (Fig. 28), and then onwards in the same direction till it reaches *e m* (Fig. 27). This brings more and more of the northern hemisphere into the shade, so that each part in revolving is more of its time on the dark side of the terminator, and its day gets

shorter till the terminator gets to *e m*. There the sun ceases its motion south, and begins to retrace his steps from *p* by E to *n*, which causes the terminator also to retrace its course, and move back from *e m* by N S to *d o*. This gradually brings more and more of the northern hemisphere into the illumined half, so that each part in revolving is less of its time on the dark side of the terminator, and its day gets longer till the terminator comes to *d o*, when it begins to move back, and the same series of changes occur again.

512. The exactly opposite series of changes goes on in the southern hemisphere.

513. This is partly illustrated by Fig. 25, page 97, where the sun is represented on its way south, now perpendicular to a point further south than the tropic of Cancer, and the terminator has advanced to *i v*, towards the north pole, and receded from the south pole. Thus, the day and night will not vary so much as when the sun is on the tropic, and a smaller circle around each pole will have constant night or constant day.

The following is a summary of these changes.

514. On June 21, the sun is on the north tropic, the north hemisphere is most turned towards the sun, and it is therefore long day north of the equator, and shortest day south of it. The day gradually shortens in the northern hemisphere and lengthens in the southern till the 22d December, when the sun is on the south tropic, and the southern hemisphere is most turned towards the sun, and it is longest day in the south hemisphere, and shortest day in the north hemisphere. From this position the day gradually shortens in the southern hemisphere, and lengthens in the northern hemisphere, till the 21st of June, when the same series of changes recommence. The days and nights have been equal all over the world at the two times when the sun, in passing south and north again, was on the equator; September 22 and March 20. Thus, the sun oscillates backwards and forwards between the tropics. At the tropic of Cancer, he is highest above the hoiizon to those north

of the equator; at the tropic of Capricorn, highest to those south of the equator. When on the equator, the sun appears at the same elevation, at corresponding latitudes north and south.

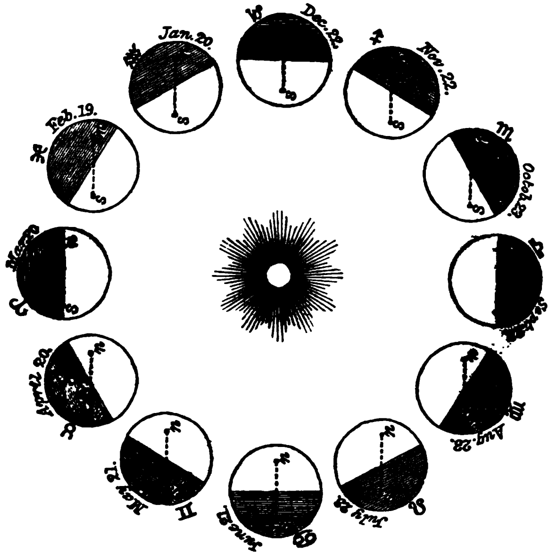
Causes of these Differences and Changes.

515. Three causes unite to produce these differences in the length of day and night at different places and different times.—1. The earth's annual motion round the sun. 2. The earth's axis being *inclined*, and not perpendicular, to the plane of its orbit. 3. The earth's axis remaining always parallel to itself in all parts of its orbit (374-5). These causes place the earth and sun in successive relative positions, which give rise to these changes.

516. From the axis of the earth being inclined to the plane of its orbit, one pole *leans towards* the sun at one period, while the other is *turned from* the sun; when the earth has moved from that point round one quarter of its orbit, the axis will be placed sideways with respect to the sun, and each pole will be equally inclined towards the sun. As the earth advances and completes another quarter, the poles now reverse their relative positions; the pole formerly turned towards the sun is now turned from it; and the other leans towards the sun. On completing another quarter, the axis will be again placed sideways towards the sun. As the earth proceeds onwards it gradually gets into the position which it occupied at first.

517. This will be better illustrated by the following figure. Let the twelve circles represent the earth in twelve different parts of its course round the sun. Let the line *n s* represent the axis of the earth, *n* being the north pole, *s* the south pole. The terminator is seen always perpendicular to the sun, but varying its position with respect to the axis *n s*, which points, in all the positions, in the same direction. At the top is seen the position on December 22, the north pole within the dark half, and *turned from* the sun, the south pole in the

Fig. 29.

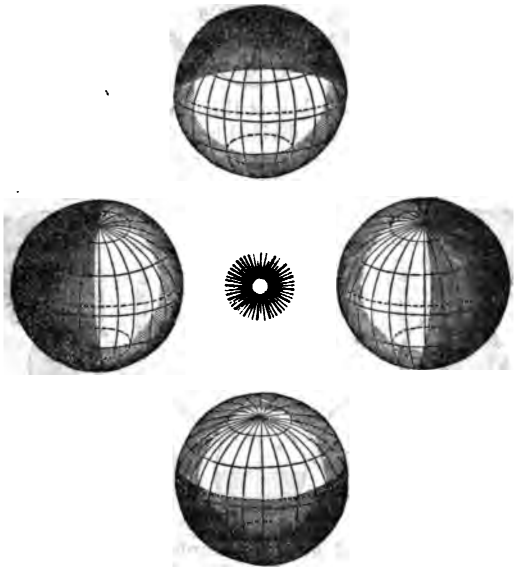


illumined half, and *leaning towards* the sun. At the left and right, the positions on March 20 and September 23 are represented, the terminator passing through the north and south poles, and the axis lying sideways towards the sun, so that each pole is equally under the sun's influence. At the bottom is seen the position on June 21, the north pole in the sun's rays; the south pole in the shade.*

518. The following figure will illustrate still better the state of the different parts of the earth at different seasons in regard to light and shade. The perpendicular straight line

* An attentive study of the preceding figure, and of the inclination of the axis to the terminator, will convey a precise idea of the various changes. The figure is irregular as a drawing, being a mixture of plan, section, and perspective, but gives a clear view of the effect of the earth's motion round the sun, on the relation of the terminator to the different hemispheres.

Fig. 30.



represents the earth's axis, its two extremities being the two poles. The terminator is distinctly seen, the gently curved line between the dark and light parts. The north pole is shown at the upper part in each of the four positions, with all the meridian lines radiating from it. At the top it is seen entirely enveloped in darkness, and so that the earth's rotation about its axis does not bring it at all out of the shade. At the sides, the terminator is seen passing through both poles, the axis lying sideways towards the sun. At the bottom, the north pole and regions around it are seen entirely in the illumined part, having continual day. The upper position represents December 21, the lower June 21, the *solstices*; —the two sides, March 20 and September 23, the *equinoxes*.

519. The date at each position in Fig. 29, shows the period when the earth gets into each position; and the

accompanying character is the astronomical mark for the *sign*, or part of the *zodiac* in which the sun appears at the time of the earth entering into each position. Of course, the earth, as seen from the sun, would appear in the opposite sign.

520. The ZODIAC, or belt of the heavens in which the sun appears to move, is divided into twelve equal parts of 30° each, termed *signs of the zodiac*. They are as follows, with the time of the sun's entering into each.

Ascending.	ARIES, the Ram,	♈,	Northern Signs.	March 20.*	Equinox—Equal day and night.
	TAURUS, the Bull,	♉,		April 20.	
	GEMINI, the Twins,	♊,		May 21.	
Descending.	CANCER, the Crab,	♋,		June 21.	Summer in the Northern Hemisphere.
	LEO, the Lion,	♌,		July 23.	
	VIRGO, the Virgin,	♍,		August 23.	
	LIBRA, the Balance,	♎,	Southern Signs.	Septbr. 23.	Equinox—Equal day and night.
	SCORPIO, the Scorpion,	♏,		October 23.	
	SAGITTARIUS, the Archer,	♐,		Novbr. 22.	
Ascending.	CAPRICORNUS, the Goat,	♑,		Decbr. 21.	Summer in the Southern Hemisphere.
	AQUARIUS, the Waterman,	♒,		Janu y. 20.	
	PISCES, the Fishes,	♓,		Febr y. 18.	

* These periods change slightly—the times given above are those of the year from March 1841 to February 1842, inclusive.

521. The sun does not enter into the constellations of the same name as the signs at the same periods as formerly, owing to the precession of the equinoxes (193-4).

522. Thus, the effect of the earth's motion round the sun is to make the latter appear to oscillate backwards and forwards between the highest and lowest positions, shown in Figs. 27 and 26—that is, from being perpendicular to the tropic of Capricorn, *c p*, 23° 28′ south of the equator, on December 22,—to being perpendicular to the tropic of Cancer, *c v*, 23° 28′ north of the equator, on June 21, crossing the equator twice during these oscillations, at March 20 and September 23.*

523. The sun, when he reaches one of these *tropics*, turns, and retraces his course,—hence the name tropic (215). And, as he appears to pause before turning, hence the name *solstice*, applied to the period when the sun is on any of the tropics (213)—December 22, the *winter solstice*—June 21, the *summer solstice*.

524. The signs of the zodiac in which the sun appears when he is north of the equator are called the *northern signs*; those when he is south of the equator, *southern signs*; those in which he is passing in a northerly direction are called *ascending*; those in which he is going south, *descending*. —See table, page 108.

525. The sun is about 7 days, 16 hours, 50 minutes longer in the northern than in the southern half of the ecliptic; being about 187 days in the northern signs, 179 days among the southern signs.

2. *Climate.*

526. The CLIMATE of a place signifies the prevailing character of the weather at that place.† This, as is well known, is very different at different places.

527. The leading circumstances which determine the character of the climate are,—1. The latitude of the place; that is, its distance from the equator: 2. The height of the place above the level of the sea: 3. Its

* From *a* to *o*, Fig. 10, page 25; and then back from *o* to *a*.

† That is, the temperature, moisture, atmospheric pressure, winds, electric condition of the air.

position with respect to large tracts of land or water: 4. The character of the prevailing winds.—The first of these only can be regarded as an astronomical cause; and it alone requires consideration in this work.

528. The climate is warmest about the equator, and becomes gradually colder as the place is further north or south from the equator, that is, as the latitude increases.

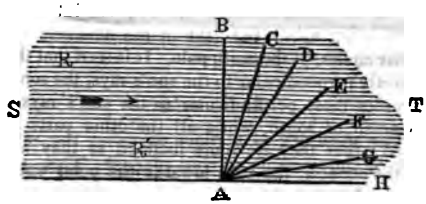
529. This rule is only true *generally*, and of large changes in latitude. Considerable deviations from it are produced by the other causes.

530. The position of the different latitudes, *in respect to the sun's rays*, is the cause of these differences in climate.

531. The heat at any place is in proportion to the number of the sun's rays which fall upon it; and the number of rays which it receives depends upon the *direction in which they fall.* Any surface receives more rays the more perpendicularly they strike upon it, and less, in proportion as the rays fall more obliquely; that is, as the angle they form with it is further from a right angle.

532. This may be illustrated by the following figure.

Fig. 31.



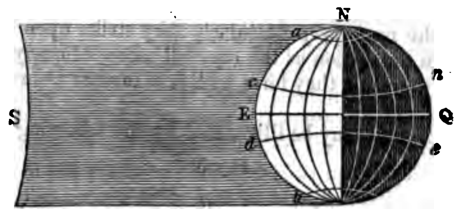
Let R and R' be rays proceeding in the direction from S towards T, and falling upon the equal surfaces A B, A C, A D, A E, A F, &c., all lying in different directions. It is plain that more rays fall upon the surface A B, which is perpendicular to the direction of the rays, than on any other; that A C, which is nearest to the perpendicular, receives more than A D, A D more than A E,

and so on; more rays being received in proportion as the surface is nearer to being perpendicular to the rays.

533. As the sun (522) oscillates between the tropics, continually vertical to some parallel in the torrid zone, his rays always fall perpendicularly at some parallel between the tropics, and less so as the parallel is further north of the north tropic, or south of the south tropic. Accordingly, more rays are received in a given space at the torrid zone, than in an equal space north or south; so that the temperature is always higher there than any where else. And as fewer rays are received in proportion as the place is further to the north or south, the heat must diminish in these directions.

534. This is illustrated by the following figure. Let S represent the sun, E the earth's equator, *c*, *d* the tropics, *a*, *b*

Fig. 32.



the polar circles, N the north pole. It is seen that the equator is perfectly perpendicular to the sun's rays, the zone between the tropics more perpendicular to the sun's rays than any parts north or south, while all the other parts are much inclined; that they are more inclined as they are further from the equator, the rays towards the poles only skirting the ground.

535. The air absorbs part of the sun's rays,—little in the upper strata, but a considerable portion in the dense lower strata loaded with vapour. Hence, less of the sun's rays strike upon a place in proportion to the quantity of atmosphere through which they pass, and in proportion to the density of that atmosphere. Perpendicular rays pass through least of the air before com-

ing to the ground. Oblique rays not only pass through more air, but through a larger proportion of the dense parts, so that a much greater portion is absorbed before they strike the soil.

536. The diminution of the mean temperature in passing from the equator to the poles is in proportion to the square of the cosine of the latitude. The change is, therefore, slight from the equator towards either tropic, greatest about lat. 45°—and slight from the polar circles to the poles.

3. *The Seasons.*

537. That regular alternation of different kinds of weather which takes place at any place during the year is termed *change in season*.

538. The same causes which give rise to the change in the length of the day and to differences in climate, produce the change in the seasons. The sun imparts more heat in proportion; 1. as he is higher above the horizon of a place, and his rays fall more perpendicularly; 2. as he is longer in the day above the horizon of a place. In the northern hemisphere, the sun rises higher and remains longer above the horizon, from March to September: we have warm weather, or SUMMER, then. From September to March the sun's rays fall in a more slanting direction, and he is a shorter time daily above the horizon: there is cold weather, or WINTER then, in the northern hemisphere.

539. The southern hemisphere is in exactly the reverse state then—summer during our winter:—winter during our summer.

540. This is illustrated by Figs. 26 and 27. In Fig. 26 the sun's rays fall more perpendicularly on the northern hemisphere, and slantingly on the southern hemisphere. In Fig. 27, the reverse is seen. In Fig. 28, and Fig. 32, the relative position of the sun and earth at the equinoxes is shown—the sun vertical at the equator, the rays more and more slanting as the place is further north or south.

541. It is evident that if the axis of the earth were per-

pendicular to the plane of its orbit, each parallel would always be turned in the same degree towards the sun, and would therefore have *no change in its seasons*. It is the inclination of the axis that causes the same parallel to lie differently towards the sun in different parts of the orbit. Hence, in a planet such as Jupiter or the moon, where the axis is perpendicular to the plane of the orbit, there can be no change in seasons; while in Venus, where the axis is very much inclined (353), the change is very great,—so great that a marked difference prevails between the state of the equatorial regions at the equinoxes and solstices. From this, the equatorial regions have *two winters* at the solstices, and *two summers* at the equinoxes. The same prevails on the earth in a slight degree—but it is very marked at Venus, from her tropics being so far from her equator (353).

542. The sun being nearer to the earth in our winter than in our summer, it might be supposed that the weather should be warmer over all the world then. But this makes no difference; for, as much heat is lost by our more rapid motion in winter as is gained by our greater proximity to the sun then; and in summer, while there is less heat from our greater distance, this is compensated for by our slower motion.

543. The warmest part of the season is not when the sun is highest and longest above the horizon; nor the coldest, when the sun is lowest and the day shortest—but some weeks after these periods. The reason of this is, that the heat must *increase*, so long as the earth receives more heat during the day than it parts with during the night; and this is the case for a considerable time after the longest day; and that the temperature must *decrease*, so long as more heat is lost during the night than is gained during the day; which goes on for several weeks after the shortest day.

544. In like manner, the warmest part of the day is not at noon, when the sun is highest, and his rays fall most perpendicularly, but some little time after, about 2 P.M. The reason is, that till that period the heat received is greater than what is lost,* so that the temperature must rise till that time, although less heat is received then than at noon.

* It must be observed that *heat is at all times passing out from*

SECTION V.

TRADE-WINDS, AND THE TIDES.

545. There are certain uniform and continual motions of the atmosphere and the ocean, which are produced by astronomical causes, and are therefore proper subjects of consideration in a treatise on Astronomy.—These are the *Trade-winds* and the *Tides*.

1. *Trade-winds.*

546. In certain districts between the tropics, the winds blow regularly in a north-east and south-east direction,—*north-east* north of the equator, *south-east* south of the equator. These steady winds are called the TRADE-WINDS.

547. The trade-winds are caused by the great currents which are continually rushing from the polar and temperate regions towards the equator, modified by the earth's rotation from west to east.

548. Owing to the great heat which prevails in the equatorial regions, the air there is expanded, and therefore specifically lighter than the air further north or south; which, being colder and heavier, rushes towards and displaces the warm air of the torrid zone. This produces continual currents towards the equator from the north and south latitudes. These are the source of the trade-winds, which, were there no other cause influencing them, would be in a due north and due south direction.

549. Now, the air from any place partakes of the motion of the earth at that place; and the parts have most rapid motion in proportion as they are nearer the equator (being there furthest from the axis—303). Accordingly, any current of air which proceeds towards

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bodies, and that a body's temperature depends upon the proportion between what is received and what is given out: rising in temperature if heat is absorbed more rapidly than thrown off, and falling in temperature if more heat is given out than is received.

the equator, will have a slower rotatory motion than the parts to which it is tending. *It will therefore cause an apparent current in a direction opposite to that in which the earth is moving*—that is, appear to blow in an *easterly* direction, as the earth revolves in a westerly direction. The easterly direction which the wind thus acquires, combined with its *northerly* direction, gives the invariable *north-easterly* wind in the *northern hemisphere*—combined with its southerly direction in the southern hemisphere, gives the *south-east* trade-wind which is found south of the equator.

550. If we suppose the air at any place to be at rest while the earth continues its rotation, an individual at that place would experience a wind in the direction opposite to its motion, as the effect is the same whether the air move and the individual stand still—or the air stand still and the individual rush against it. Now, it will be the same sort of effect, though less in degree, when the air is moving *in the same direction as any part of the earth's surface, but with a slower motion*—the place will overtake it, rush against it, and cause a wind in an opposite direction. If this air have, besides the slow motion in the *same direction*, another in a different direction, the two will be compounded into a middle course, according to the law of the composition of forces. Thus it is with the current which produces the trade-wind. It has a *slow westerly* motion, which produces an easterly wind in a place having a *rapid westerly* motion; which easterly wind, combined with its north or south motion, gives the north-east or south-east trade-wind.

551. As the distance from the axis increases very little in the vicinity of the equator, the rotatory motion will increase very slightly there, and there will be little addition to the easterly direction of the current created about the equator; and as the air gradually acquires the motion of the parts it is over, it will have acquired the increased motion of the equatorial parts by the time it reaches them; the easterly direction will diminish as they come near the equator, and the north and south currents meeting there, the two will neutralize each

other; accordingly, comparative calm, or irregular breezes prevail in the immediate vicinity of the equator.

552. The heated air which ascends from the equatorial regions gradually descends towards the earth's surface; and, bringing to the parts where it descends a higher velocity than they possess, moves in advance of them, in the same direction, and constitutes a sort of trade-wind; which, compounded of the westerly motion of rotation and the motion from the equator, gives a south-westerly direction in the temperate regions of the northern hemisphere: a north-westerly direction in the temperate regions south of the equator.

553. These are the leading causes which give rise to the trade-winds. They are modified in various ways by many local circumstances, which do not come under consideration in Astronomy.

2. *The Tides.*

554. By THE TIDES we mean that regular succession of rise and fall of the surface of the waters of the globe, which is observed in all the great oceans, and in the seas and rivers which freely communicate with the oceans.

555. "It is a very remarkable operation of nature, that we observe on the shores of the ocean, when, in the calmest weather and most serene sky, the vast body of waters that bathe our coasts advances on our shores, inundating all the flat sands, rising to a considerable height, and then as gradually retiring again to the bed of the ocean; and all this without the appearance of any cause to impel the waters to our shores, and again to draw them off. Twice every day is this repeated. In many places, this motion of the waters is tremendous, the sea advancing, even in the calmest weather, with a high surge, rolling along the flats with resistless violence, and rising to the height of many fathoms." —*Robinson's Mechanical Philosophy.*

556. When the waters rise to the highest point which they reach in the course of the day, it is said to be HIGH WATER, or FLOOD, and the rising is called the FLOOD-TIDE; when at the lowest, LOW WATER, or EBB, and the fall is termed EBB-TIDE. The highest or fullest *flood*,

is called a SPRING-TIDE; the lowest *flood*, is termed NEAP-TIDE. The tide on the side of the earth next the moon, is called the SUPERIOR-TIDE; that on the opposite side, the INFERIOR-TIDE.

557. The phenomena of the tides are produced by the joint action of the moon and the sun upon the waters of the ocean; chiefly by the moon. The attractive force of these bodies is sufficiently strong to draw slightly towards them those parts of the earth which are moveable, and whose particles can easily be made to slide over each other;—that is, the waters.

The following are the leading phenomena of the tides.

558. (1.) The waters when at their highest, gradually sink till low water, then rise again till it is high water, then sink again, rise again, and so on unremittingly. Upon an average, the tide ebbs in about 10 minutes less than the time it takes to rise, and remains stationary for a little at ebb and at flood. The whole period between two successive *floods*, or between two successive *ebbs*, is about 12 hours 25 minutes. The interval between two successive floods is 12 hours 19 minutes at new and at full moon; 12 hours 30 minutes at the quarters.

559. Thus, during every 24 hours and 50 minutes there is high water twice, and low water twice at every place, and the flood is about three quarters of an hour later every day. Hence, therefore, as the earth turns half round in that time, 12 hours, there must be high water at the opposite parts of the earth's surface at the same time—that is, at the two places having the same meridian circle (or on the opposite meridians, reckoned by their numbers).

560. (2.) The height of high water, as well as that of low water, varies very considerably, but regularly. But, when the tide rises highest, it falls lowest, and when it rises least, falls least. At Plymouth, there is sometimes a difference of 21 feet between high and low water; sometimes only 12 feet.

561. The highest or *spring-tide* occurs once every

fortnight, and is usually about the third or fourth high tide after new moon, and the third after full moon—from about a day and a half to two days and a half after these periods.

562. The lowest tide,* or *neap-tide*, also occurs once every fortnight, being the third or fourth high tide after the moon is in her quarters—from about a day and a half to two days and a half after these periods.

563. The tides gradually decrease from about new moon to the first quarter, increase from the first quarter to full moon, decrease from full moon to the third quarter, and again increase from the third quarter to new moon.

564. (3.) There is also a *monthly* period of change in the height of the tides: the highest spring tide is that which occurs when the moon is in *perigee* (221); and the next spring tide is the smallest, occurring when the moon is in *apogee* (221). The force of the moon's attraction being the main cause of the tides, it is to be expected that they will vary somewhat as her distance varies.

565. (4.) The height of the tides is also affected by the following causes: the sun's distance;† the elevation of the sun and moon; the latitude of the place; and local circumstances, such as banks in the ocean, and the form and elevation of the shores, channels, currents of rivers, winds, &c.

High Water at the Part nearest to the Moon.

566. The chief cause of the phenomena of the tides is the *force of the moon's attraction*. This force is greater in proportion as the body attracted to the moon is nearer to her. Therefore, the waters directly under the moon (*i. e.* at the place where the moon is on the meridian) will be more attracted than those at other parts, and

* That is, when the water falls least and rises least.

† The greatest tides are during the winter of the northern hemisphere, the sun being nearest to the earth then. Also, the tides are highest in the latitudes about the equator,—the least within the polar circles.

will be raised towards her, while the waters at the sides, where the moon appears in the horizon, will be drawn towards that part and aid the accumulation; forming *high water* there. As, by the earth's rotation and moon's motion, the moon comes on the meridian of each place once in 24 hours 50 minutes, there will be high water every where once in every period of 24 hours 50 minutes.

567. The period of high water will not be exactly when the moon is on the meridian and her action strongest; for, the impetus the waters have received, and the continuance of the moon's action (still strong, though decreasing) cause them to continue rising for some time after. The period of high water, therefore, is usually (local causes being disregarded) about three hours after the moon is on the meridian.

Low Water where the Moon is in the Horizon.

568. As the moon tends to draw the waters in straight lines towards her, she will evidently draw off the surface, or depress the waters on which she acts sideways; *i. e.* those parts at which she appears in the horizon 90° on each side from the meridian she is on; this will cause *low water* at these two places once every 12 hours 25 minutes.

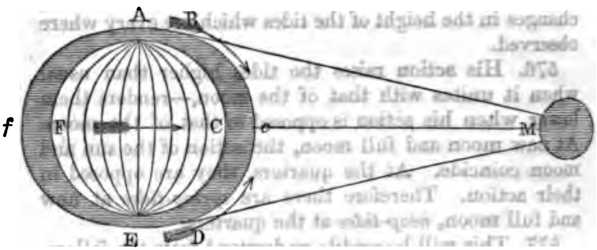
High Water at the Part furthest from the Moon.

569. As the moon attracts the earth, as well as the loose waters on its surface, she will tend to draw the earth *from* the waters which are on the side of the earth most distant from the moon. As she attracts the earth more forcibly, being nearer, than those distant waters, she will draw the earth further towards her than those waters. This will cause the earth to recede from under these waters, which causes them to rise relatively to the land at those parts, and thus there is high water there also. As the moon comes into this position every 24 hours 50 minutes, there will be high water at the part farthest from the moon once in every period of 24 hours 50 minutes.

570. This accounts for the TWO TIDES daily; each part, by the earth's daily rotation, being brought once *near* to and once *remote* from the moon during each 24 hours 50 minutes.

571. The following diagram will illustrate the action of the moon upon the waters.

Fig. 33.



Let A B C D E F represent the earth, M the moon, C the point nearest to the moon, F the meridian farthest from the moon, A and E the points at which the moon appears in the horizon, 90° east and west from C and F; then there will be high water at C and F; low water at A and E.

572. The moon's attractive force at C evidently tends to raise the waters towards *c*, and to draw them from A to B, E to D, and from B and D towards *c*; as shown by the arrows in Fig. 33. Also, as the moon's force draws the earth from F with more force than it draws the waters at F, the earth must recede from these loose waters and cause them to be proportionally elevated. Hence, there is high water at C, where the moon is on the meridian, and also at the opposite meridian F.

573. But the moon's action evidently draws the waters *from* A and E, and tends to make them low at these points: while these waters tend also to rush towards F, where, from the earth's recession, the waters are lighter. These two causes depress the waters at A and E, and there is therefore low water there.

574. The action will be readily understood, if we reflect on the simple law of the diminution of the force of attraction as the distance increases; and bear in mind that the earth is less attracted by the moon than the waters near her, but more than the waters more remote.

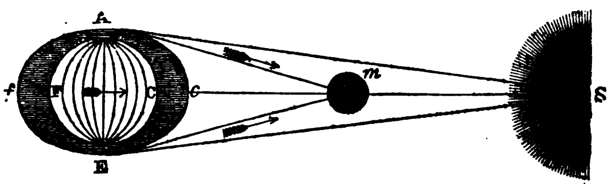
Sun's Action upon the Tides.

575. The sun also by his action influences the waters of the ocean, and is the main cause of those regular changes in the height of the tides which are every where observed.

576. His action raises the tides higher than usual when it unites with that of the moon,—renders them lower when his action is opposed to that of the moon. At new moon and full moon, the action of the sun and moon coincide. At the quarters, they are opposed in their action. Therefore there are *spring-tides* at new and full moon, *neap-tides* at the quarters.

577. This will be readily understood from the following figures.

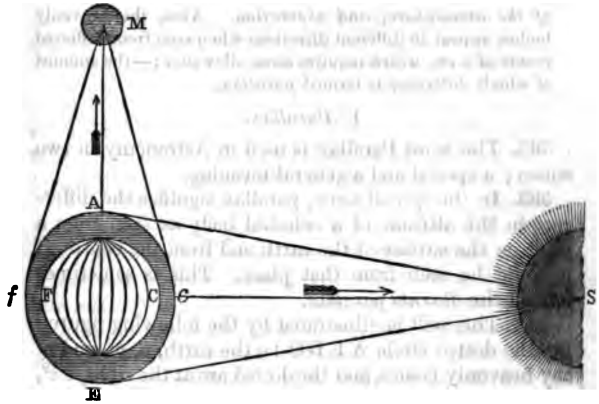
Fig. 34.



If S represent the sun, M the moon, and f A c E the earth, then, as the sun and moon act in the same manner and in the same direction, it is evident that the effect upon the waters will be increased, or there will be a *spring-tide* at c and f, and a very low tide at A and E. Both sun and moon tend to raise c and f, to depress A and E.

578. But if the moon be in one of her quarters, as in Fig. 35, then they act in opposition to each other. The sun tends to draw the waters towards c from A and E; and thus prevents the tide at A and E from being so

Fig. 35.



high, and that at *c* from being so low,—or forms *neap-tides*. The moon tends to raise A and E, to depress *c* and *f*,—the sun exactly the reverse.

579. The ratio of the sun's action on the tides to that of the moon is as 1 to 3, or 1 to $2\frac{1}{2}$.

580. The Baltic sea has no perceptible tides; and that in the Mediterranean sea is very slight. These seas have no tides in themselves, because, being of comparatively small extent, the moon's action is equal at every part; and, they do not receive the influence of the Atlantic tide, because their entrances are narrow, and do not lie in the direction of the current produced by that great tidal wave.

SECTION VI.

PARALLAX—INFLUENCE OF THE ATMOSPHERE ON ASTRONOMICAL PHENOMENA—ABERRATION.

581. There are some causes which prevent the heavenly bodies from appearing in their true positions, and the effect

of which, therefore, must be allowed for in judging of their real, by their apparent, situation. These are, *the influence of the atmosphere, and aberration.* Also, the heavenly bodies appear in different directions when seen from different points of view, which requires some allowance;—the amount of which difference is termed *parallax.*

1. *Parallax.*

582. The word Parallax is used in Astronomy in two senses; a special and a general meaning.

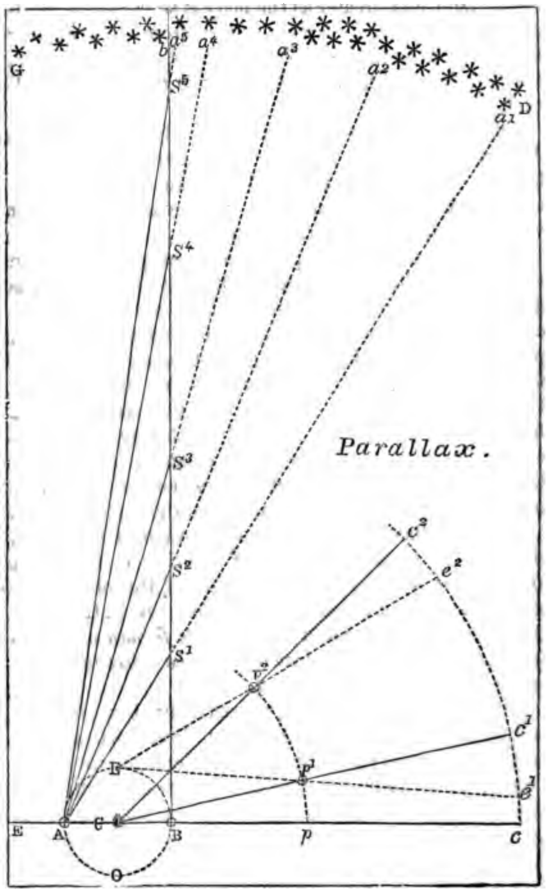
583. In the special sense, parallax signifies the difference in the altitude of a celestial body as seen from a point on the surface of the earth and from the centre, if it could be seen from that place. This is sometimes termed the *diurnal parallax.*

584. This will be illustrated by the following figure: Let the dotted circle A E B O be the earth, p, p^1, and p^2 any heavenly bodies, and the dotted arc at the right, $e\,c^2$, the imaginary surface of the heavens to which we refer the positions of celestial objects. Let E be the position of an observer on the earth's surface. Now, if the heavenly body p^2 be viewed from E, it will appear at e^2 on the surface of the heavens, as shown by the dotted line $E\,p^2\,e^2$; but if viewed from C, the earth's centre, it would appear at c^2, as shown by the line $C\,p^2\,c^2$. The difference of these two positions is the arc $c^2\,e^2$, which is therefore termed the parallax at E of the body p^2; or, instead of the arc $c^2\,e^2$, the angle $c^2\,p^2\,e^2$, which the arc $c^2\,e^2$ subtends, and which is of the same number of degrees (46), may be called the parallax of p^2 at E. Or, the angle $E\,p^2\,C$, which is equal to the angle $c^2\,p^2\,e^2$, may be called the parallax of p^2 at E. The latter is what is usually stated as the parallax of the object.

585. Thus, the parallax of a celestial body is the angle at it formed by two lines, one drawn to it from the earth's centre, the other from the observer's position on the earth's surface.

586. The effect of parallax is to depress the body, always making it appear nearer to the horizon than when seen from the centre. This is evident, as c^2, the

Fig. 36.



position of p^2 as seen from the centre, is nearer the zenith of E than e^2, its position as seen from E.

587. Parallax is always greatest when the body is *in* the horizon, and greater as the body is *nearer* to the horizon of the observer. This is evident from the preceding figure, in which the parallax, $c^2 e^2$, of p^2, is less than $c^1 e^1$, the parallax of p^1, which is nearer to the horizon of E than p^2.

588. There is no parallax of a body in the zenith. This is evident from the preceding figure, in which the body p, which is in the zenith of an observer at B, appears in the same position in the heavens, c, whether viewed from B or from the centre.

589. As bodies must appear in different positions when viewed from different points of the earth's surface, it is desirable for astronomical and nautical purposes to calculate their apparent position in reference to some fixed point: this being known, a correction can be applied for the difference in the apparent position as seen from the surface and that given as the position seen from the fixed point. The point selected for this purpose is the earth's centre, and the ordinary meaning of parallax, therefore, is the difference in the positions of a body as seen from the earth's surface and from the earth's centre.

590. Parallax, in the wider acceptation of the term, signifies the apparent change of position in an object arising from a change in the position of the observer—sometimes termed its *parallactic motion*. As in the above case, it may be expressed by *the angle formed at the object by two straight lines drawn from the object to the two points from which it is observed.*

591. When an object is viewed from two different points, it will appear in different directions at these points. And the exact amount of difference will be expressed by the angle at the object formed by the two lines of view (585). Thus, in Fig. 36, page 124, if A and B in the dotted circle below represent two positions from which the object S^1 is seen, that object will be seen in the direction A S^1 from A and B S^1 from B. The angle A S^1 B will be the amount of difference in the directions A S^1 and B S^1, or the parallax of S^1.

592. The parallax of any object diminishes as its distance increases; and a body may be so remote that its parallax will become so small as to be insensible.

593. This is illustrated by Fig. 36, page 124. Let A and B be two points from which the bodies S^1, S^2, S^3, S^4, S^5 are viewed. As the distance increases, the angle at the body diminishes, A S^2 B being less than A S^1 B, A S^3 B being less than A S^2 B, and so on. It is evident that if the distance from the line A B were very much increased, the angle at the body would disappear altogether, the lines to it from A and B would coincide, and the distance from A to B would be as nothing compared with their distance from the object.

594. Now, it is by means of the parallax of a heavenly body that its distance is calculated. The distance between the two points being known, and the angle of its parallax, trigonometry furnishes the distance from the position to the object.

595. The parallax of any body increases as the distance between the points of view increases. This is evident; for if the observer at B were to shift his position to the right till he came to *c*, then the angle A S^3B would be very much increased, as the line from S^3 to B would now be in the direction from S^3 to *c*; and thus a body too far distant to give a discernible parallax at two points might give a very sensible parallax if the distance between the two points of view were very much increased.

596. Now, none of the fixed stars give any parallax with the radius of the earth; it is therefore known that their distance is infinite when compared with that radius, and that with it alone we have no means of measuring the distance of a fixed star. Therefore, a much longer basis has been tried—the longest which we can command,—the radius of the earth's orbit. But none of the fixed stars give any parallax even with this extended basis: they have no *annual parallax* as it is termed: the earth's orbit shrinks to nothing compared with the enormous distances of these glittering points; and we have no means of ascertaining the distance of a

fixed star, but can only determine that it is not less than a certain quantity.

597. Now, if the angle of parallax in this case were so small as one second (1″), it would be discernible by our means of measurement, and the distance of the body would be more than 200,000 times that of the basis. The basis being ninety-five millions of miles, the distance, with the smallest discernible parallax, must be upwards of nineteen millions of millions of miles. But the parallax is less than that; therefore the nearest of the fixed stars whose parallax has been attempted must be at a greater distance from us.

598. BESSEL, a German astronomer, is said to have ascertained the parallax of the star 61 Cygni to be about one-third of a second, 0·348″. If this be the case, this star must be at a distance of 519,200 times the radius of the earth's orbit; and its light must take about nine years to reach us.

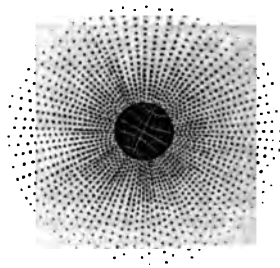
599. That distant objects give no parallax with points near each other is very obvious in the case of any short distances on the earth with the moon. For example, looking at one limb of the moon along two parallel streets, it will be found to appear in the very same direction along either street. The angle of parallax is too small to be discernible; the two lines from the street to the moon coalesce; the distance between the two points of observation is a mere point compared with their distance from the moon; and we could not, with that distance as a basis, measure the moon's distance. The same may be observed of an object on earth. If an individual walk along a road for any given distance, and take some very remote object, such as the stars, or a far-off tower or mountain, whereby to judge of the apparent motions of bodies between his line of motion and the fixed objects by which he judges of their apparent motions, he will find that these various bodies will have shifted their apparent position less and less according as they are further from him,—that is, their *parallax* will be less. In proportion as they are more remote, he will find the angle at the body, formed by two straight lines drawn to the two points of view, become less and less, till it disappears, and the two lines coalesce; then there is no parallax, and, with that basis, *no means of measuring the distance of the object.*

2. *Influence of the Atmosphere on Astronomical Phenomena.*

600. The heavenly bodies are rendered visible to us by rays of light which emanate from them and produce impressions of their forms on the eyes of the observer. These rays are somewhat modified in their course before they reach us by passing through the atmosphere.

601. The atmosphere is an aerial fluid, which surrounds the earth on every side. It extends above the surface to a height of about forty-five or fifty miles. It is heavy and dense in the lower regions, but becomes gradually lighter and more rare or expanded as it is further above the surface; as represented in Fig. 37, where the particles are shown densely crowded near the surface, and becoming more open as they are further above the surface.

Fig. 37.



602. The atmosphere is concerned in astronomical phenomena by its power of *refracting* and *reflecting* the rays of light.

603. Refraction is that bending of the rays of light which takes place when they pass obliquely from one medium* to another. If a ray of light pass *obliquely* from air to water, from water to air, from surrounding space to our atmosphere, or between strata of different densities of the same medium, it does not continue in the same straight line as before, but is bent, more or less, into another direction, which it preserves so long as it continues in the same medium.

604. Refraction is illustrated by the following figure.

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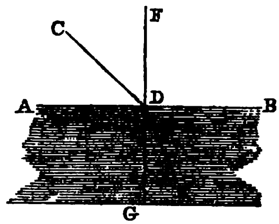
* Any fluid through which any influence is transmitted is called a medium in reference to that influence, as air to light.

Fig. 38.



Let C D represent a ray of light passing at D from a rare into a dense medium, to the surface of which it is not perpendicular. It will not continue in the direction of C D, but will be bent into the direction D E. If the ray had come from the dense medium in the direction E D, entering the rare medium at D, it would be bent into the direction D C. Let the line G D F be perpendicular to the surface between the two media; then, it will be evident from the figure that the following is the rule of refraction :—

"When the ray passes into a denser medium, it is refracted so as to be nearer to the perpendicular than before; when it passes into a rarer medium, it is refracted so as to pursue its course further from the perpendicular than before."

605. If the ray entered perpendicularly, as in the direction G D or F D, it would not be refracted, but would continue in the same course, G D F, or F D G.

606. Owing to REFRACTION, no heavenly body is seen in its true place unless it be in the zenith. Every where else, refraction causes bodies to appear to be higher above the horizon than they really are.

607. This takes place in the following manner: When a ray of light enters the atmosphere obliquely, it is bent down towards the surface of the earth, and as it approaches the ground, it becomes more and more bent in passing from the rarer strata above to the denser medium below. Now the object from which the ray comes appears *in the direction which the ray has at the moment when it strikes the eye.* Accordingly, as refraction in a denser medium bends the ray towards the perpendicular direction, the object will be seen in a direction more

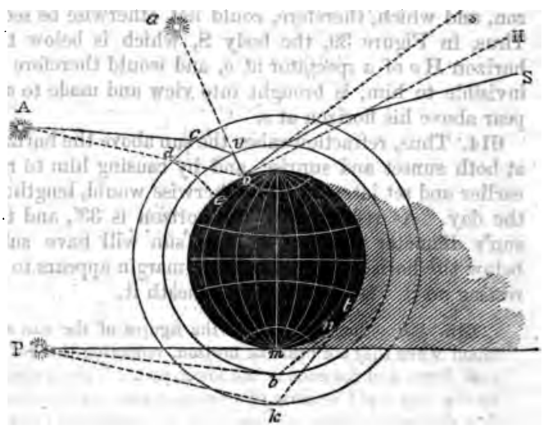
perpendicular to the surface than its real one—that is, nearer the zenith, or more elevated above the horizon than it should be.

608. Refraction is very slight on the ray first entering the atmosphere, owing to its extreme tenuity in the upper regions; but gradually increases as the ray approaches the earth, the strata of air becoming more and more dense.

609. As the rays from a celestial object in the zenith enter the atmosphere perpendicularly, there can be no refraction of its rays, and it will be seen in its true place. But, from every other position, the rays will enter the atmosphere obliquely, be refracted, and therefore represent it too elevated.

610. The following figure illustrates atmospheric refraction. Let *o* represent any point on the earth's surface, and A any star or heavenly body. It is seen at *o* by means of rays of light from it which reach the eye,—by those rays from A which enter the atmosphere at *c*

Fig. 39.



They are refracted to *c e*; and, as the air becomes more dense, to *v e*, which is the direction they have on reaching the surface. Accordingly, the star is seen as if it were in this direction, which represents it not at A, but at *a*.

611. The course of the ray from *c* to *o* should be a curve, as the air gets gradually and insensibly denser. The ray from A, which would have rendered the object visible at *o* had there been no refraction, viz. A *d*, is refracted down to *e*.

612. Refraction increases as the object is nearer the horizon, as the rays then pass through more of the dense strata of air. At the zenith, it is 0°, 0′, 0″. At 45° above the horizon, it elevates the apparent above the true position of a celestial object about 1′—more correctly 57″. At the horizon, it elevates the object so much as 33′, or about half a degree—that is, about as much as the sun's apparent diameter (368).

613. Refraction, by elevating the position of celestial objects, brings into view bodies actually below the horizon, and which, therefore, could not otherwise be seen. Thus, in Figure 39, the body S, which is below the horizon H *o* of a spectator at *o*, and would therefore be invisible to him, is brought into view and made to appear above his horizon at *s*.

614. Thus, refraction raises the sun above the horizon at both sunset and sunrise, and by causing him to rise earlier and set later than he otherwise would, lengthens the day. As refraction at the horizon is 33′, and the sun's diameter is about 32′, the sun will have sunk below the horizon when his lower margin appears to us resting on it, just about to dip beneath it.

615. Refraction also distorts the figures of the sun and moon when they are near the horizon, rendering them of an oval form, and flattened at the lower part. This is caused by the very rapid increase of refraction near the horizon, so that the lower margins of these orbs are much more elevated than the upper, which shortens the perpendicular diameter, and gives the figure a somewhat oval shape.

616. The REFLECTION of light signifies the bounding

off of rays of light from bodies on which they strike: this takes place in the same manner in which a ball rebounds from any hard surface on which it is thrown, or in which sound and heat are reflected.

617. The atmosphere reflects, and disperses in all directions the rays which it receives from the sun. Were there no atmosphere, those bodies only would be visible to us which are in the direct rays of the sun, and thus receive light, which they would transmit to us and render us sensible of their presence. But, by the reflective power of the atmosphere, bodies have light thrown upon them, though out of the direct course of the sun's rays; and thus, as the atmosphere is every where present, they receive light in whatever position, which they in turn reflect to us, and thus render themselves visible.

Of Twilight.

618. TWILIGHT is the faint and gradually diminishing light which we enjoy for a considerable time after the sun has fairly sunk below the horizon; and we are indebted for twilight to the reflective power of the air. Those portions of air which are a little nearer to the sun than any place at which the sun has just set, will reflect down to that place (as well as to the parts which have had the sun still longer below the horizon) a part of the light which they receive; accordingly, that place will, for a little after sunset, receive an inferior degree of light reflected from the air,—or twilight. And, as it will receive reflected light from a less body of air as the sun sinks lower below the horizon of a place, its twilight will diminish gradually till total darkness supervenes.

619. This is illustrated by the lower part of the above figure, page 130. Let the sun, P, be on the horizon of the place *m*, having completely set to *n* and *t*. These places, *n* and *t*, would be completely dark were there no atmosphere. But, though the sun is far below the horizon of *t*, it will receive a small portion of light reflected from the upper air at *k*, and from all the air above the shaded line and beyond the line *k t*. The earth at *n*,

not so far out of the sun's rays, will receive reflected light from a much larger portion of atmosphere ;—viz. from *b*, lower down, and from all the air above the shaded line and beyond the line *b a*.

620. Twilight continues while the sun is less than 18° below the horizon. Hence, some parts of the earth have continual twilight at certain periods of the year; as at London, from May 22 to July 21. There is shorter twilight the nearer the place is to the equator—there the twilight continues for about 1 hour 12 minutes. The *real*, or astronomical twilight, is of much longer duration than what is popularly regarded as twilight; for it commences immediately after the sun is below the horizon, when there is still good daylight, and continues for some time after it is apparently dark.

621. The duration of twilight is short in tropical regions, and longer as we approach the poles. The rapid rotation of the parts about the equator, and the great distance from the axis, bring, very soon, a considerable convexity between the sun and the spectator, so that the period of reflection is cut short.

Aberration.

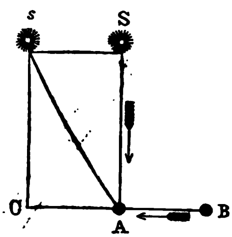
622. Aberration is an *apparent displacement* of the celestial bodies from their true position, arising from the motion of the earth in its orbit, and the time required by light to traverse space.

623. Every object is seen in the direction which the rays from it have when they strike the eye, *if the eye be at rest*. But, if the eye be in motion, the direction in which the object is seen will be one compounded of the direction of the eye's motion and that of the rays from the object (242). The difference between the real direction of the object and that in which it appears is called the aberration.

624. Let A, Fig. 40, be the position of an observer, and S, the position of a star. Let B be the situation of the earth, when that ray emanates from S, by which the star is seen at A,—the earth and ray coming to A

at the same instant. Then, by the composition of motion, the star, when the earth comes to A, will appear at *s*, in advance of its true position. The angle SA*s* is the aberration. As SA, which represents the motion of light, is very great compared with BA or AC, which represents the earth's motion in the same time (as 192,000 to 19), the aberration is very small.

Fig. 40.



625. The aberration is greatest, when (as in Fig. 40) the direction of the ray is perpendicular to the direction of the earth's motion: in this position, there is a displacement, by aberration, to the extent of 20″·5 (twenty seconds). It diminishes from this till the directions of the two motions are parallel, when it ceases altogether.

626. There is also some aberration from the motion of the parts by the earth's rotation; but this is insensible. In the aberration of the planets, allowance has to be made for their motion.

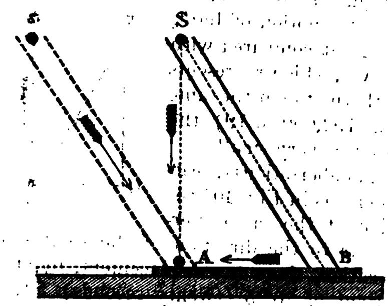
627. Had the earth been stationary at A, or had light come instantaneously from S to A, the star would appear in its true position, at S.—The phenomenon of aberration is one of the most convincing proofs of the earth's motion round the sun; and it confirms very satisfactorily Roemer's discovery of the progressive motion of light, and also the rate of its motion as inferred from the eclipses of Jupiter's satellites.

628. Aberration may be illustrated by the manner in which drops of rain strike upon an individual, according as he is in motion or at rest. If the drops fall perpendicularly, and he be at rest, they will be felt only on his head,—that is, *they will strike in the direction of their own motion.* But if he be moving quickly, they will strike upon his face, and *appear to be coming in a slanting direction* TOWARDS *him,* as if they fell from a point not only *above* him but in *advance* of him. It is evident, that the direction in which

they would appear to come must depend upon the *real directions* and *comparative velocities* of the two motions.

629. Or, if we conceive a ball to be let fall perpendicularly in the direction S A, Fig. 41, and to enter the tube S B,

Fig. 41.



which has a motion in the direction B A sufficient to carry it to the position A *s* in the same time in which the ball would fall from S to A; then the ball would, while passing from S to A, move in the axis of the tube, and to an observer at the bottom of the tube would necessarily appear to have come from *s*, not from S, and to move in the direction *s* A, not S A. The ball is analogous to the ray of light, the bottom of the tube to the earth, and the direction in which it appears to move to the direction in which the star is seen.

630. For the discovery of the aberration of light, and determination of its amount, science is indebted to the distinguished English astronomer DR BRADLEY (in 1725).

SECTION VII.

PRECESSION OF THE EQUINOXES—NUTATION OF THE EARTH'S AXIS.

631. Besides its rotation on its axis, the earth has two other motions which change the direction of the parts with-

out altering the position of the whole in space, called *Precession* and *Nutation*. These motions are very slow, and are not discoverable except by very careful and long-continued observation.

1. *Precession of the Equinoxes.*

632. The ecliptic cuts the equinoctial in two points, called the EQUINOXES (211), during one revolution of the earth round the sun. But THESE TWO GREAT CIRCLES CUT EACH OTHER IN DIFFERENT POINTS EACH YEAR; that is, the points (or stars) in the starry heavens where they intersect are different each year. This change in the position of the equinoxes is called *the precession of the equinoxes*.

633. The line of the equinoxes moves backwards* upon the ecliptic, that is, from *east* to *west*, or in a direction contrary to the sun's apparent annual course through the ecliptic, which is from west to east; so that each year the sun crosses the equinoctial in a point *west* of that in which they last met. The amount of this retrocession is $50''\cdot10$ every year.

634. As the sun moves eastward through the ecliptic, and the equinox moves westward, the sun will come sooner to the equinox in each revolution, for they move round towards each other; hence the period of each equinox will come a little earlier every year; from which the expression *precession of the equinoxes* is derived. The time which the equinox precedes each year is $20^{m.}\ 19\cdot9^{s.}$, that being the time in which the sun goes through an arc of $50''\cdot1$.

635. From this circumstance, the positions of the signs of the zodiac among the stars change regularly backwards (in the opposite direction to the sun's motion). The rate at which the equinox recedes is such, that it makes a complete revolution round the ecliptic in 25,868 years. This is equal to $1°$ in $71\cdot6$ years,

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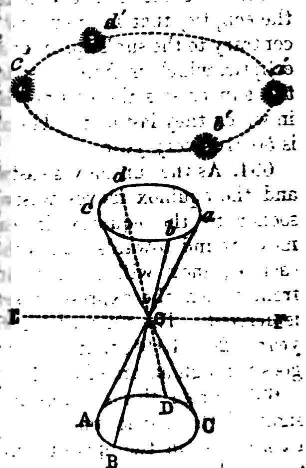
* A motion from west to east, or in the order of the signs, is said to be *direct;* from east to west, or against the order of the signs, *retrograde* or *backwards*.

or 30° (one sign) in about 2000 years. And accordingly it is found that the position of the equinox is now about 30° behind what it was 2000 years since; for then the *signs* and *constellations* of the same name were the same,—but each sign, which still retains the name it had then, is now in the preceding constellation.—See Par. 131, page 29, and Par. 194, page 42.

636. From this recession of the equinox, the true year, or the period of the earth's return to the same star, is a little longer than the equinoctial or tropical year, which is the interval between two returns to the same equinox.—See "Year" in the section on the "Divisions of Time."

637. The precession of the equinoxes is caused by a *conical motion of the earth's axis*, by which, while the middle point remains fixed, the poles describe a small circle, as in the adjoining figure. Let A *a*, B *b*, C *c*, D *d*, represent the earth's axis, O being the middle point. It does not always remain in the same direction, pointing to the star *a'*,—but shifts on its centre, passing from A *a* to B *b*, &c., the poles describing the circles A B C D, *abcd*, and successively pointing to the stars *a'*, *b'*, *c'*, *d'*.

Fig. 42.



Thus, each radius describes a cone—completing it in the long period of 25,868 years. The radius O A describes the cone O A B C D,—the radius O *a*, the cone O *a b c d*.

638. The motion of each radius exactly resembles that of a top spinning. It is often observed, besides its rotatory motion, to have a swinging motion, inclining to one side,

then gradually shifting, and inclining as much all round, so that its axis has a compound motion, turning like any revolving body, and at the same time describing a cone of which the apex is at the ground. In this swinging motion, it always keeps the same inclination to the horizon, as the earth's axis does to the ecliptic.

639. From this, the pole of the heavens (the point in the heavens towards which the earth's pole is directed) describes a circle round the pole of the ecliptic (Par. 62); this circle is always 23° 28′ from that pole.

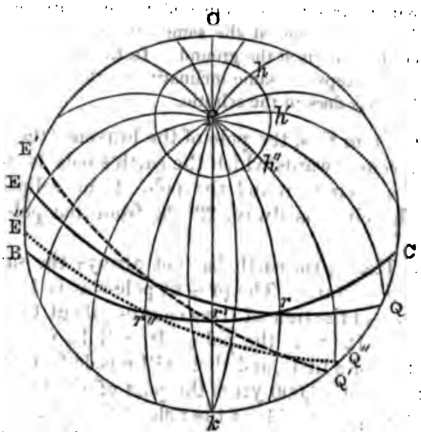
640. Hence, the earth has not always the same star for its pole-star.* The present pole-star is 1° 24′ from the pole—at the time of HIPPARCHUS (about 140 B.C.) it was about 12° from the pole. It will be nearer to the pole still for a little, and then will recede from it again; and in about 12,000 years the pole of the heavens will be on the opposite side of the pole of the ecliptic, 46° 56′ from its present position, and very near VEGA, the principal star in the constellation LYRA, which star will then serve for a pole-star. See Fig. 42, in which the axis is seen pointing successively to the different stars a', b', c', d' in the sphere of the heavens.

641. But the angle of inclination of the axis to the ecliptic always remains unchanged; so that the angle between the planes of the ecliptic and equinoctial still continues the same—23° 28′. And the whole earth partakes of this motion, so that the axis and poles still bear the same relative position to the other parts of the earth's surface,—the latitudes remain the same, and the waters are unaffected.

642. From this, then, the points where the ecliptic and equinoctial cut each other must be continually shifting. This will be illustrated by the following figure. Let P represent the pole of the ecliptic, the sphere representing the sphere of the heavens. Let B C be the ecliptic, and

* The brightest star near the pole of the heavens, is the pole-star at the time.

Fig. 43.



the small circle $h\,h'\,h''$ the circle in the heavens marked out by the earth's pole round the pole of the ecliptic, and the points $h\,h'\,h''$ on that circle different positions of the pole of the heavens. When h is the pole, the equinoctial will be E r Q, intersecting the ecliptic in r. When h' is the pole, $E'\,r'\,Q'$ will be the equinoctial, cutting the ecliptic in r'—and when the pole is at h'', the position of the equinoctial will be $E''\,r''\,Q''$, having r'' for the equinox.

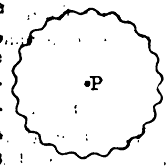
643. The cause of this conical motion of the earth's axis is the action of the sun and moon upon the protuberant matter at the earth's equator. As they move in the ecliptic (191), and the projecting matter at the equator is out of the plane of the ecliptic, their action tends to draw this towards the plane of the ecliptic and to make the planes of the ecliptic and equator coincide. But the rotation of the earth on its axis prevents any change in the inclination of the equator and ecliptic; and causes the earth to have the gyratory motion in its axis which gives rise to precession.

644. The amount of precession caused by the action of the sun is about 15″·1; that produced by the moon 35″, or, nearly, as 2 to 5.

2. *Nutation.*

645. The circle which the earth's pole describes round the pole of the ecliptic is not a true circle, but waved, or undulating, as represented in the adjacent figure. This oscillatory motion of the pole backwards and forwards is termed NUTATION, being a sort of nodding motion of the earth's axis.

Fig. 44.



646. Nutation will be best understood by supposing the point representing the *mean place of the pole* to describe the uniform circle round the pole of the ecliptic, while the *real position* of the pole describes a small circle (or rather ellipse) round the mean place.

647. This small ellipse is completed in a little less than nineteen years, at a distance from the mean place of the pole of about 9″—the longer axis of the ellipse, which points towards the pole of the ecliptic, being about 18″·5.

648. Nutation is caused by the action of the moon on the protuberant parts at the earth's equator, which, as the moon's orbit is inclined 5° 9′ to the ecliptic, and its nodes complete their revolution round the ecliptic in eighteen years seven months, causes the above described motion, accompanying that of precession.

SECTION VIII.

DIVISIONS OF TIME.

649. The leading divisions of time are, THE DAY, THE MONTH, and THE YEAR. The civil standard, in the

reckoning of time, is the MEAN SOLAR DAY of twenty-four hours; that is, the mean or average time which the earth takes in revolving from the moment when the sun is on the meridian of a place till he returns to that meridian again. The most perfect measure of time is the sidereal day, or the time which the earth takes in revolving from the moment when any star is on the meridian of a place till it returns to the same meridian.

1. *The Day.*

650. There are four different kinds of days. 1. The sidereal day. 2. The solar day. 3. The mean solar day. 4. The lunar day.

1. SIDEREAL DAY.

651. The true or sidereal day is the time of one complete rotation of the earth on its axis,—and its length is 23 hours, 56 minutes, 4·09 seconds. It is called "sidereal" from *sidus* a star, because it is determined by the interval between the two successive appulses of any star to the same meridian.

652. The true time of the earth's rotation on its axis is judged of from the return of a star to the meridian, because the distance from the earth to the fixed stars is so great, that its position in *any different parts of its orbit may be considered always the same with respect to any fixed star*. Hence, in reference to the fixed stars, the earth may be looked on as not moving round the sun at all, but *ever remaining in the same spot*, rotating at a uniform rate upon its axis, and therefore ever returning to any star in the same time.

2. SOLAR DAY.

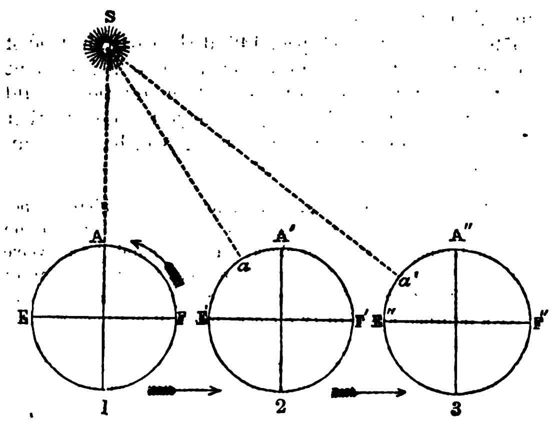
653. The solar day is the time from the sun's being on the meridian of a place till he returns to that meridian,—in other words, the interval between two successive appulses of the sun to the meridian.

654. The solar day is longer than the sidereal day, and its duration is different at different periods of the year.

655. The solar day is longer than the sidereal day, because, while the earth's motion onwards in its orbit *makes no sensible change in its position in relation to the fixed stars, it makes a material difference in its position in relation to the sun.* This affects the solar day in the following manner: After the earth has made one complete turn on its axis, and brought any meridian on which the sun was at the commencement of that rotation to the same star, *that meridian will not have reached the sun at the close of the rotation;* for, the earth has during that period moved onward in its orbit, and, having in a manner *moved past the sun,* must turn further round than the complete rotation to bring that meridian to the sun again.

656. This may be illustrated by the following figure. Let S represent the sun, E A F, a section of the earth

Fig. 45.



at the equator, A the meridian on which the sun is at any given time. If the earth revolve on its axis in the direction F A E, as indicated by the arrows, and move in its orbit from 1 to 2 in the time in which it turns on

its axis, it will have moved to 2 when the point A or A′ has come to the same star; but as it has moved so as to bring the sun in a manner *behind* the earth's new position, it will not have brought that point to the sun, but require to move round to *a* before it comes again to the sun. Hence, the solar day is longer than the sidereal day by the time the point A′ takes in revolving from A′ to *a*.

657. The length of the solar day is different at different periods of the year from two causes:—1. The inequality in the rate of the earth's motion round the sun;—2. The inclination of the earth's axis to the plane of its orbit.

658. As the earth does not always move at the same rate round the sun, it will, at different times, have moved different distances during one rotation, and therefore the excess over the complete rotation necessary to bring a point back to the sun will be more at certain times than at others.

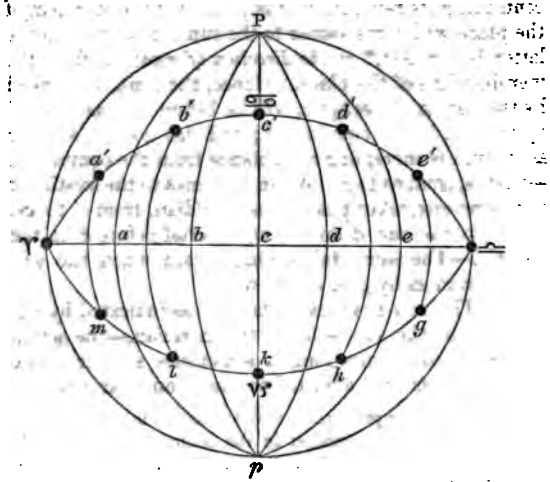
659. Thus, in Fig. 45, page 142, if the earth, instead of moving from 1 to 2, had moved from 1 to 3, it is evident that the point A, or A″, at the end of one rotation, would be still further from the sun, and have to move further besides the complete rotation to bring A to have the sun on its meridian—namely to *a′*.

660. Perhaps the best illustration of the difference between the solar and sidereal days is afforded by the motion of the hands of a watch or clock. If both hands be at twelve o'clock, and set out together from that point, the long or minute hand, when it has made a complete revolution, will have returned again to 12 o'clock, but will not have reached the hour hand, because it also has been moving, though more slowly, in the same direction; and the long hand will have to go more than the complete circle before it overtakes the short hand. Now, the long hand resembles any terrestrial meridian, the short hand the sun, and the dial plate and figures the starry sphere and stars. If the hour hand be supposed to move at different rates in different parts of its circuit, the minute hand must take different periods to come up to it.

661. The inclination of the earth's axis to the plane of its orbit affects the length of the day by causing the earth to move in a plane inclined to that of its equator; that is, inclined to the direction of the earth's rotatory motion, which is parallel to its equator.

662. This will be best explained by the supposition that (as it really appears) the sun moves round the earth in the ecliptic, while the earth turns daily on its axis; and that while the real sun moves in the ecliptic, another, which marks uniform time, moves in the equinoctial. With these suppositions, and the aid of the following figure, the inequality caused by the sun being in the ecliptic may be comprehended. Let the figure

Fig. 46.



represent the sphere of the heavens, ♈ c ♎ the equinoctial, and ♈ c′ ♎ the ecliptic. Let the real sun be supposed to move from ♈ by *a′ b′ c′ d′ e′* ♎ *g h l m*, returning to ♈ in the year, while the other, starting at the same time from ♈, moves along the equinoctial by

$a\,b\,c\,d\,e$ ♎, returning again in the opposite direction in the year. The ecliptic and equinoctial are both great circles of the same sphere, and hence are equal to each other. Let each be divided into the same number of parts in a, a', &c.; then, as the whole circles are equal, the parts in one will be equal to those in the other, and therefore the part ♈ a' of the ecliptic is equal to the part ♈ a of the equinoctial, $a'\,b'$ to $a\,b$, $b'\,c'$ to $b\,c$, and so on.

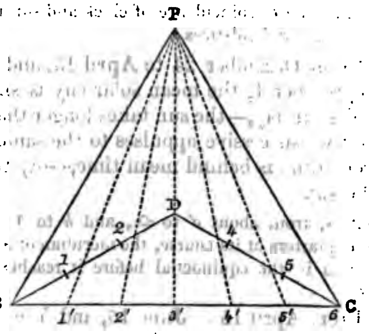
663. Now, let the meridian of any place and the two suns be on ♈ at any given moment—then all set out together in the same direction, *i. e.* towards ♎. When the place has completed its daily revolution and returned to ♈, the two suns will have advanced in their course, let us suppose to a' and a, equal distances from ♈,—in continuing its revolution, it is plain that the meridian of the place will come sooner to the sun a' than to a, as the latter is furthest,* *in the direction of rotation*, from the meridian line of the place. Hence, the time, as marked by the sun in the ecliptic, will be before that as marked by the sun in the equinoctial; and this goes on so long as the sun is increasing his distance from the equinoctial —that is, from ♈ to c'. When he comes to the solstice at c', the reverse takes place; the meridian, from c' to ♎, comes to the sun d on the equinoctial before d' in the ecliptic.—The same takes place again when the sun moves from ♎ by g, h, &c. to ♈.

664. The SUN-DIAL exhibits time as indicated by the real time of the sun being on the meridian,—the actual solar day, sometimes longer, sometimes shorter. The CLOCK exhibits time adjusted to the mean solar day.

665. The comprehension of the variation in the day being caused by the sun's motion in the ecliptic, will be greatly aided by marking points on the equinoctial and ecliptic at equal distances from the equinox, on a terrestrial or celestial globe, and observing in what order they come to the brazen meridian, according as they are approaching to or receding from the equinoctial. It may be rudely illustrated by making

* The distance of a point from a line is the perpendicular on the line drawn from the point.

Fig. 47.



a figure such as the above,—fixing by a pin one end of a thread at P, and causing it to pass from P B to P C. The thread, in passing from P B to P 3′ will always come sooner to any point in B D than to a corresponding one in B 3, and the reverse in passing from P 3′ to P C. Now P represents the pole, the thread the meridian of a place, B D C the ecliptic, B C the equinoctial.

3. MEAN SOLAR DAY.

666. The mean time occupied by the earth in revolving from the sun's being on the meridian of a place till it returns to the same meridian, is called the *mean solar day*. It is this to which the clocks are adjusted, so that they may give equal time at all periods of the year.

667. Four times a-year, the *mean solar day* and *actual solar day* are the same. Then, the clock (mean solar day) and sun-dial (actual solar day) are coincident. These four times are, December 24th, April 15th, June 15th, September 1st.

668. These periods are near the equinoxes, but do not coincide with them. Did the variation in the solar day depend solely on the inclination of the earth's axis to the ecliptic, the periods of the clock and sun being the same would be the equinoxes and solstices; but the other element

which gives rise to variation in the solar day—the inequality in the rate of the earth's motion round the sun—causes the time of coincidence of clock and sun to vary from the equinoxes and solstices.

669. From December 24 to April 15, and from June 15 to September 1, the mean solar day is shorter than the actual solar day,—the sun takes longer than 24 hours between two successive appulses to the same meridian, —apparent time is behind mean time,—or, the clock is *before* the sun.

That is, from about c' to ♎, and k to ♈ in Fig. 46. In these quarters of its course, the meridian of a place comes to the sun in the equinoctial before it reaches that in the ecliptic.

670. From April 15 to June 15, and from September 1 to December 24, the actual solar day is *shorter* than the mean solar day,—the sun occupies less than 24 hours between two successive appulses to the same meridian, —apparent time is before mean time,—or, the clock is behind the sun.

That is, from about ♈ to c', and ♎ to k, Fig. 46, a place in its daily revolution comes sooner to the real sun in the ecliptic than to the imaginary sun we have supposed to revolve in the equinoctial.

671. See column "Equation of Time" in the almanacs; which shows how much the clock is before or behind the sun every day of the year, so that when we take the true time by an observation of the sun's altitude, we may be able to add or subtract the necessary time to set the clock by mean time.

672. Generally speaking, it may be said that from about the time of the equinoxes, the clock is behind the sun,—from about the time of the solstices, the clock is before the sun. The days vary so much, that sometimes apparent noon is $16\frac{1}{4}^{m.}$ before mean noon,—sometimes $14\frac{1}{4}^{m.}$ after mean noon.

673. Although the sidereal day never varies, it cannot be adopted as the standard of time for ordinary occasions of life; because, it would not conform with those natural di-

visions into day and night (periods of sunshine and periods of darkness) from which, for the sake of convenience, our arrangement of time cannot depart far. As the stars always come to the meridian at the same successive intervals, and the sun does not,—if the hours were regulated by the sidereal day, the same hour would now be at sunrise, now at noon, now at sunset, continually changing its relation to the occurrence of those changes of the day and night, by which it is most convenient to divide our time.

4. LUNAR DAY.

674. The lunar day is the interval between two successive appulses of the moon to the same meridian. This is different from the true day, as the moon has a motion through the heavens, so that the earth has to make more than a complete rotation before she brings any meridian again round to the moon. As the moon moves daily about 13° through the sky, to overtake which the earth requires about 50 minutes, this time must be added to the common day to constitute a lunar day; which is therefore $24^{h.}$ $50^{m.}$ in duration.

2. *The Month.*

675. The month is of three kinds,—The *sidereal*, or *periodical month*, of 27 days, 7 hours, 43 minutes; the *synodical*, or *lunar month*, of 29 days, 12 hours, 44 minutes, being the interval from one new moon to the next (387, 384); and the calendar, or common month, January, February, March, &c., 31 or 30 days, excepting February, which is 28 or 29 days. In each year there are 12 common or calendar months; a little less than 12½ synodical months; and a little less than 13½ sidereal months.

3. *The Year.*

676. The year is of five kinds,—1. The EQUINOCTIAL, or TROPICAL YEAR;—2. The SIDEREAL YEAR;—3. The ANOMALISTIC YEAR;—4. The COMMON YEAR, of 365 days;—5. The LEAP-YEAR, of 366 days.

1. THE TROPICAL YEAR.

677. The period of time adopted for the astronomical year is the interval between two returns of the sun to the same EQUINOX; called, therefore, the equinoctial year. Its duration is 365 days, 5 hours, 48 minutes, and 49·7 seconds.

678. The CALENDAR or COMMON year contains 365 days. The odd hours, $5^{h.}\ 48^{m.}\ 49{\cdot}7^{s.}$, would soon accumulate to a serious amount of error: they are disposed of in the following manner: They amount to nearly a quarter of a day, and are allowed to accumulate till *every fourth year*, when they amount to a day, and are got rid of by making that year one day longer, or 366 days. That additional day is added in February, which has then 29 days; and that year is called LEAP-YEAR, or BISSEXTILE. This and other important improvements were introduced by JULIUS CÆSAR; according to the plans of the astronomer SOSIGENES.

679. But the excess of the tropical year over 365 days is not quite a quarter of a day, being about 11 minutes less; hence one day every four years is too much to add. This is compensated for, within a very trifling quantity, *by making every hundredth year a common year, except the fourth, which is to be a leap-year.* Thus, in every four hundred years, three years, which would otherwise be leap-years, have only 365 days, which takes off the excess of the day added in each leap-year over four times $5^{h.}\ 48^{m.}\ 49{\cdot}7^{s.}$ The remaining error amounts only to one day of excess in 3866 years.

680. The principle of arrangement may be thus shortly stated. Every common year which leaves no remainder when divided by 4 (as the year 1840), and every hundredth year, which leaves no remainder when divided by 400 (as the year 2000), are leap-years, having 366 days. All the others are years of 365 days.

681. This arrangement was introduced by Pope Gregory in 1582, and has been adopted in all civilized countries, except Russia. It was introduced into Great Britain in 1752,

—being termed the *new style*. The error had then accumulated to 11 days, and was rectified by advancing the days of the month 11 days; the 3d of September to be the 14th. The difference between the new and old styles now amounts to 12 days.

2. THE SIDEREAL YEAR.

682. The true time of the earth's revolution in its orbit, is the period of its return to the same star. After the sun has returned to the same equinox, as that has receded 50″·1, he has still 50″·1 of his orbit to complete the real revolution, which requires 20m. 19·9s. of time, which must therefore be added to the tropical year to make the sidereal year. The duration of the latter is therefore, 365d. 6h. 9m. 9·6s.

3. THE ANOMALISTIC YEAR.

683. The line of the earth's apogee and perigee—that is, the longer axis of the orbit, undergoes a gradual change, which shifts the apogee 11″·8 annually. The earth, therefore, must describe this small arc in addition to its real revolution to bring it round to the same position with respect to the apogee. It requires 4m. 39·7s. to complete this small arc, and therefore the anomalistic year—as the time required to bring the earth to the same relative position to the apogee is called—is 4m. 39·7s. more than the sidereal year, or 365d. 6h. 13m. 49·3s.

SECTION IX.

MOON'S PHASES—ECLIPSES, &c.

1. *The Moon's Phases.*

684. The leading phenomena of our satellite the moon have been already mentioned: see page 79.

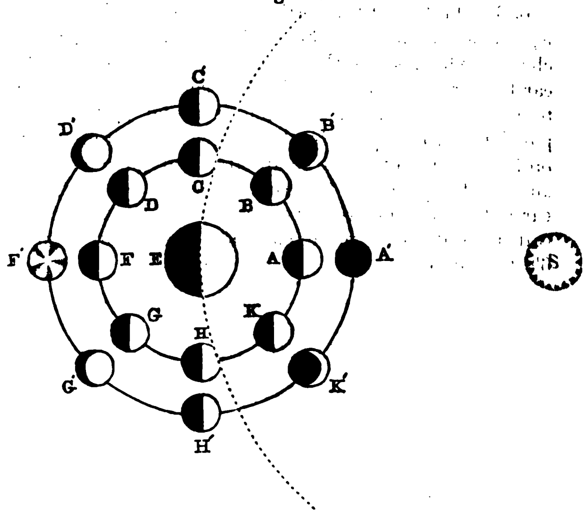
685. The changes in the moon's appearance from a small illumined crescent to that of a full enlightened

orb, and from that to a crescent again till she disappears entirely, are termed PHASES.

686. The moon's phases are owing to the following causes. She is a dark body in herself, and shines only by reflecting the sun's light; so that only one half of her surface—that which is next the sun—is illumined at a time: and the only parts that can be seen are those parts of the illumined half, which are turned towards the observer. But, owing to the moon's motion round the earth, different amounts of the bright half are turned towards the earth at different times, so that she appears of every different magnitude, from full moon till she disappears altogether.

687. The following figure will illustrate the moon's phases, and also those of Mercury and Venus.

Fig. 48.



Let S represent the sun, E the earth, and A, B, C, D, F, G, H, K, in the inner circle, the moon, revolving

round the earth in the direction of the order in which the letters have just been named. Then at A, when the sun and moon are in conjunction, the unenlightened half of the moon is turned towards the earth, as shown at A′ in the outer circle, and the moon is not seen; or, *it is new moon;* or, as sometimes expressed, *the moon changes.* At B, as is seen by the points where the inner circle cuts the moon, a small part of the enlightened side comes into view to the earth; but the greater part of the side turned towards the earth is dark, and the moon appears an illumined crescent, as shown at B′, in the outer circle. At C, half of the enlightened part is turned towards the earth, the moon appears like a semicircle, as at C′ in the outer circle. At F, the enlightened side is turned towards the earth, and the moon appears full, as at F′, being then in opposition. As she continues her course, she gradually presents less and less of her bright side to the earth, successively appearing as at G′, H′, K′ in the outer circle, until she again comes into conjunction, and entirely disappears. By tracing the figure, the phases will be readily understood. The inner circle shows the illumined and dark parts—the outer circle the appearance presented to the earth.

688. When the moon is in conjunction or opposition (as at A and F, Fig. 48), she is said to be in her SYZIGIES—when midway between these points (as at C and H, Fig. 48), in her QUADRATURES.

689. The earth appears to the moon as she does to us, but of about thirteen times the size, and affords her a very considerable degree of light. The light which the earth yields the moon renders the dark parts of the latter faintly visible, a little before and after new moon. At these periods the moon's light, as it appears at the earth, is weakest, and the illumined half of the earth most fully turned towards her. See A, K, and B, Fig. 48, page 151. This enlightens the dark part of the moon, and this light reflected back to us, renders these dark parts visible with a dull grayish light—forming the appearance popularly termed "the old moon in the new moon's arms."

690. When the moon is viewed by a telescope, mountains and valleys are distinctly discerned on its surface,—the former very numerous, and some of them about $1\frac{3}{4}$ miles in height. There is no appearance of clouds, or any indications of an atmosphere of a density at all approaching to that of the earth. When she presents less than her full enlightened surface to us, the edge next the sun, which is fully illuminated, appears smooth and rounded; while the other appears rough and broken,—most probably from the hills being still enlightened by the sun's rays, while the low grounds are dark. The same side is always turned towards us (386); but from her motion in her orbit not being uniform, we sometimes see a little of her surface beyond that half on each side; and from her axis being inclined to the plane of her orbit, we see at times a little beyond her poles. These shiftings of the face next us are termed LIBRATIONS.

ECLIPSES AND OCCULTATIONS.

691. When the sun or moon is, in whole or in part, obscured by a shadow which gradually comes over the disc and then glides off, this phenomenon is termed an ECLIPSE. Eclipses are of two kinds,—eclipses of the sun, and eclipses of the moon. When any fixed star or planet is obscured by the moon or a planet passing between it and the earth, this phenomenon is termed an "occultation."

692. Eclipses occur only when the moon is in or near to her nodes (224); because then only the moon, earth, and sun are in the same straight line, or so nearly so, that a part of one can obscure part of another. They also occur only at new and at full moon.—See Par. 704.

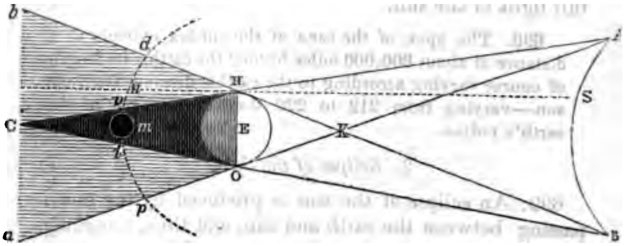
1. *Eclipse of the Moon.*

693. An eclipse of the moon is caused by the interposition of the earth between the sun and moon, so that the earth prevents the moon from receiving the sun's light, and she is therefore obscured.

694. Hence, an eclipse of the moon takes place only when she is in opposition.

695. The following figure will illustrate an eclipse of the moon.

Fig. 49.



Let A S B represent the surface of the sun, H O the the earth, *m* the moon, *d n i p* the moon's orbit. Then, the sun's rays from A and B, skirting the earth at H and O, will project a conical shadow H C O, within any part of which no rays will be received from the sun. But, the parts A and B of the sun also send rays, crossing in K, A O *a*, and B H *b*; and between the line of these rays and the perfectly dark cone H C O, any object will receive part but not be illumined by the whole of the sun's rays, part being cut off by the interposed earth. Thus, at *n*, no rays from the sun's surface between S and B will be received, and therefore a less perfect light will be shed at *n*.

696. The perfectly dark space H C O, is called the UMBRA or shade; the surrounding parts *b* H C, *a* O C, the PENUMBRA or "almost shade" (*pene* almost, *umbra* shade).

697. Now, when the moon is at *d* she will be fully illuminated, receiving the rays from the whole of the sun's surface A S B; but whenever she enters the *penumbra*, by crossing the line *b* H, the earth will cut off a portion of the sun's light, and she will receive less and less as she passes onwards towards *v*: after crossing the line H C, she is totally eclipsed, and remains so from *v* to *i*: on crossing O C, she emerges from the umbra into

the penumbra C O *a*, in which she gradually receives light from more of the sun's surface, and becomes more luminous till she passes out of it, and again receives the full light of the sun.

698. The apex of the cone of the umbra extends to a distance of about 800,000 miles beyond the earth; its length of course varying according to the earth's distance from the sun—varying from 212 to 220 times the length of the earth's radius.

2. *Eclipse of the Sun.*

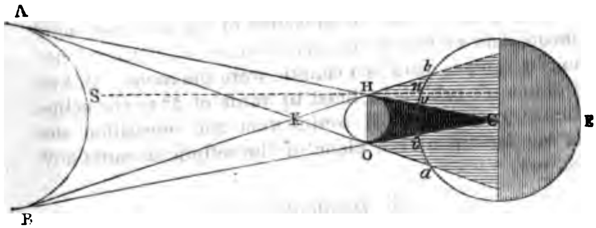
699. An eclipse of the sun is produced by the moon passing between the earth and sun, and thus, according to circumstances, cutting off a part or whole of his surface from our view. Hence an eclipse of the sun happens only when the moon is in conjunction, *i.e.* at new moon. The eclipse may be *total*, when the whole of the sun's disc is obscured; *partial*, when only a part of his surface is obscured; and *annular*, when the moon cuts off a circle in the middle, leaving a luminous ring around the part obscured.

700. The distance of the earth, sun, and moon from each other, is the circumstance which determines the nature of the eclipse. The extremity of the cone which forms the moon's umbra falls always near the earth; but sometimes falls short of the earth;—sometimes just touches it;—sometimes is so long that it could reach a point within the surface, and then there is a spot on the earth entirely obscured.

701. The following drawing will illustrate total and partial eclipses of the sun.

Let A S B be the surface of the sun, H O the moon, *ba*E the earth, H O C the umbra or dark shadow, *b* H C and C O *a* the penumbra, within which only part of the sun's surface is obscured. It is evident that within *v* and *i* there will be a total eclipse; from *b* to *v* and from *i* to *a* a partial eclipse. Thus at *n*, the moon will obscure that part of the sun's surface which lies below the line *n* H S, so that it will perceive only that part above

Fig. 50.



that line, or S A, and the extent of the sun's disc eclipsed will be greater according as the place is nearer to *v* and *i*, where the *umbra* commences.

702. An annular eclipse of the sun occurs when the apex of the cone of the moon's shadow or umbra falls short of the earth—then there is a margin of the sun's surface left bright all round, while the moon darkens the middle part.

703. This will be illustrated by Fig. 51.

Fig. 51.

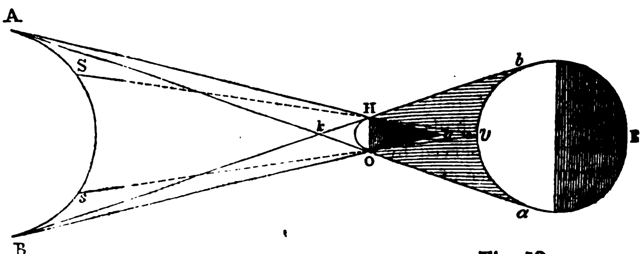
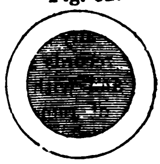


Fig. 52.



Let A S B, as before, be the surface of the sun, the apex of the conical shadow reaching only to *c*. It is plain that an observer at *v* will have part only of the sun's surface cut off from his view—namely, the part within the

letters *S s*—the parts A *S* and B *s* will be seen forming a luminous ring all round, as shown in Fig. 52.

704. There would be an eclipse of the sun every new moon, and of the moon every full moon, if the planes of the moon's orbit and ecliptic were the same. But as the moon's orbit is inclined upwards of 5° to the ecliptic, at most times of conjunction and opposition she is too far out of the plane of the ecliptic to cause any eclipse.

Occultations.

705. As the zodiac, through which the moon describes her path in the heavens, is thickly studded with stars, these will successively be obscured as the moon passes onwards, interposing between them and the earth. When the dark side of the moon crosses a star it is equally occulted, but the occultation is more sudden and striking, as its light is not previously diminished.

CHAPTER IV.

SKETCH OF THE HISTORY OF ASTRONOMY.

706. As the heavenly bodies are every where conspicuous, and naturally attract the attention;—as many of their relative changes of position are obvious, and must have been observed by even the rudest tribes;—and as the coincidence of these changes with important terrestrial phenomena could not escape observation;—astronomy has been cultivated from the earliest ages, and is by far the oldest of the sciences.

707. The origin of this science cannot be distinctly traced to any one country or people. The earliest authentic records show that it was cultivated simultaneously, and with considerable success, by the four great nations of remote antiquity, the CHALDEANS, EGYPTIANS, INDIANS, and CHINESE. The Egyptians and

Chaldeans had divided the year into $365\frac{1}{4}$ days, observed the direct and retrograde motions of the planets and that they were sometimes stationary, that the ecliptic was inclined to the equinoctial, and had the zodiac divided into twelve constellations;* besides many other important astronomical phenomena. The Chaldeans are said to have been the first who divided the day into twelve hours; and the Egyptians first used the period of seven days—the week.

708. From EGYPT, which has been justly termed the "cradle of the arts and sciences," and from CHALDEA, a knowledge of astronomy passed into GREECE. Among the philosophers of that country, and of the famous school of ALEXANDRIA, founded in EGYPT by PTOLEMY, after the death of ALEXANDER the GREAT, astronomy was cultivated with much zeal, and became enriched by a very great number of new observations, as well as important corrections of former observations.

709. THALES is the first Grecian on record who seems to have given a stimulus to astronomy. He is said to have predicted an eclipse of the sun, to have understood the nature of eclipses, to have discovered the obliquity of the ecliptic; and to have pointed out the Little Bear by which to steer as a guide to the north instead of the Great Bear. He lived about 600 B. C. He is said to have been of *Phœnician* extraction. The Phœnicians steered by the Little Bear.

710. The present view of the solar system was first promulgated by PYTHAGORAS, a famous Grecian philosopher, who flourished about 500 years before the commencement of the Christian era; and taught by his disciple PHILOLAUS. He supposed the sun to be in the centre, and the earth and planets to revolve round it; and was persecuted for holding this opinion.

711. But this opinion was not generally entertained. It was confined to *some* of the learned, and was not con-

* Some of the ancient oriental nations (Indians and Chinese) divided the zodiac into 27 portions corresponding to the moon's daily progress, called the *Houses* or *Mansions of the Moon*.

fidently taught or firmly believed by them. The majority of the philosophers of those days, as well as the people, entertained the popular notion that the sun, moon, planets, and stars, revolve daily round the earth, supposed to be fixed.

712. Though it is conjectured that the true system of the universe was known to some before PYTHAGORAS, particularly to ANAXIMANDER, it has been always termed the PYTHAGOREAN SYSTEM.

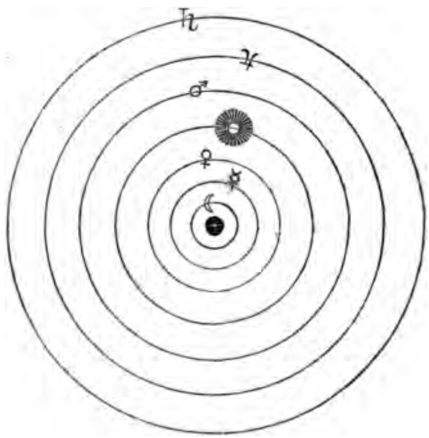
713. HIPPARCHUS, who has usually been regarded as the "Father of Astronomy," flourished about 140 B.C. He determined with greater accuracy the length of the year; discovered the inequality in the rate of the sun's motion, which he explained by supposing the earth not in the centre of the sun's orbit; observed the inequality in the length of the day; discovered the precession of the equinoxes; drew up a catalogue of the fixed stars with their precise positions; and determined the positions of places on the earth's surface by their latitudes and longitudes. He is said to have been the inventor of spherical trigonometry.

714. PTOLEMY of Alexandria, who flourished about 130 years after the commencement of the Christian era, being born in the year 69, is the next astronomer of note. He was the author of a work on Astronomy, which is still preserved, being known by the name of *Almagest*, which it received from the ARABIANS, in which the whole astronomical knowledge of the times is recorded.

715. PTOLEMY upheld the popular system, that the earth is a fixed centre round which all the heavenly bodies revolve daily. He placed the stars, sun, moon, and planets in the following order of distance from the earth:—viz. Moon, Mercury, Venus, Sun, Mars, Jupiter, Saturn, and, lastly, the sphere of the fixed stars. This was the PTOLEMAIC SYSTEM, which so long held possession of public opinion. The figure in the following page represents the

PTOLEMAIC SYSTEM.

Fig. 53.

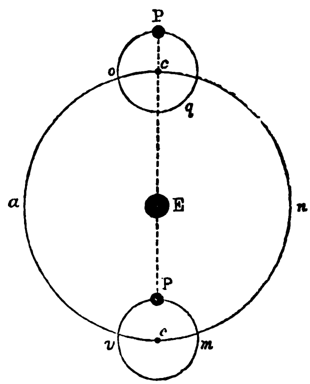


PTOLEMY argued that if the earth moved round the sun, the poles of the heavens would not always remain the same, that the fixed stars would not preserve the same figures and relative distances,* that the earth by the greatness of its mass would move faster than the loose bodies on its surface, so that they would be left behind, and that the earth would soon move out of the heavens. He objected to the earth's rotatory motion that if such were the case, clouds, birds, and bodies floating in the atmosphere would be left behind.

716. The apparently irregular and retrograde movements of the planets were explained by the theory of EPICYCLES :—namely, that the heavenly bodies revolve in small circles, the centres of which move in regular orbits round the earth. Thus, let E, in Fig. 54, be the earth, and P any planet, revolving round the earth. It is

* These objections had been removed by the suggestions of previous astronomers, that the earth's orbit might perhaps be a mere point in comparison with the distance of the stars.

Fig. 54.



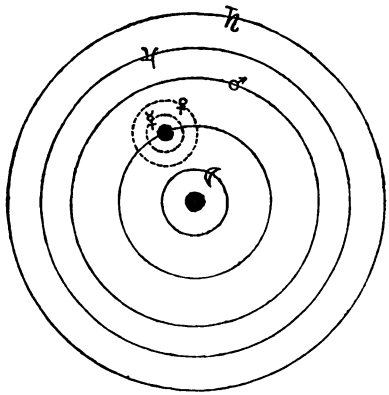
supposed to revolve in a small circle, P*oq*, round a centre *c*, which again revolves in the circle *amno* round the centre E, the earth. The small circle P*oq*, in which the planet revolves, is called an *epicycle*, and the large circle round which it turns, the *deferent*. This theory had been devised by Apollonius to explain the retrograde movements of the planets.

717. Ptolemy also entertained the *excentric hypothesis*, namely, that the earth was not exactly in the centre of the orbits of the sun and planets; by which the apparent inequality in the rate of the sun's motion was explained. He considered the earth to be spherical, and a mere point in comparison with the distance of the fixed stars.

718. It has been said that the ancient Egyptians at one period held the opinion that Venus and Mercury had the sun, and not the earth, for the centre round which they revolve, to explain the constant vicinity of these planets to the sun. This, represented in the following figure, has been termed the

EGYPTIAN SYSTEM.

Fig. 55.



719. After the time of PTOLEMY, Astronomy made little progress for more than a thousand years. It was cultivated by the ARABS, who made some additions and corrections, and some improvements in trigonometry; and through whose invasion of Spain it was introduced into Europe in the ninth century. The PERSIANS also cultivated Astronomy during this period.

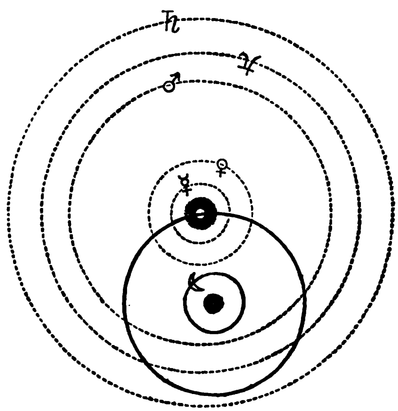
720. In Europe, Astronomy made little progress till the restoration of the true system of the planets by COPERNICUS. This distinguished man was born in Poland in 1472. He was professor of mathematics at Rome, but spent his latter days in his own country. In meditating upon the phenomena of Astronomy, he found that the Ptolemaic system did not afford an adequate explanation of them, and that the Pythagorean system accounted satisfactorily for all the changes and motions. He accordingly adopted it: and his views were published in a work called ASTRONOMIA INSTAURATA, which was published only a few days before his death, which took place in 1543. His system, called the Cop-

ERNICAN SYSTEM, has now been fully established. He made other valuable additions to Astronomy, besides restoring the true system.

721. The next astronomer of note was TYCHO BRAHE, a Dane, born in 1546. He made many important corrections of previous observations, drew up a catalogue of the stars, discovered the refraction by the air, and many important points in the motions of the moon, and ascertained the comets not to be atmospheric phenomena, by showing their great distance, &c. He devised a planetary system, in which the earth was placed in the centre,

Fig. 56.

TYCHONIC SYSTEM.



and the sun and moon were conjectured to have the earth for their centre of motion, while all the planets were supposed to have the sun for their centre. This, which has been called the TYCHONIC SYSTEM, was devised to accommodate better to the various astronomical phenomena, the idea of the earth being the centre of the whole, to which TYCHO BRAHE firmly adhered.

722. **Kepler** was born in Wirtemberg in 1570. He was a pupil of **Tycho Brahe**, on whose observations his important discoveries were founded. He hinted at some such power as gravitation, and applied it to the phenomena of the earth and moon and the tides. He developed the three great laws stated in p. 57, which may be considered the basis of the science of Astronomy.

723. The celebrated **Galileo** made great contributions to Astronomy. He was born at Florence in 1564. He invented the pendulum, discovered the spots on the sun and its rotation on its axis, ascertained that Venus had phases like the moon, and found out the satellites of Jupiter. He was a leading advocate and promoter of the Copernican system, for which he suffered much persecution; and died in 1642, having enriched Astronomy and Mechanical Philosophy with many valuable discoveries.

724. **Hevelius**, **Huygens**, and **Cassini** in the early part and middle, and **Flamstead** towards the close of the 17th century, lent considerable assistance to the advancement of astronomical science. Flamstead drew up a catalogue of the stars.

Towards the close of this century **Roemer** discovered the progressive motion of light: and Picard and the Cassinis and others made some approximations towards ascertaining the true figure of the earth by measuring the length of the degree at different latitudes.

725. **Sir Isaac Newton**, the founder of the **Science** of Astronomy, was born in England in 1642. He published in 1686 his immortal work, in which he developed the great laws of universal gravitation, and applied them to the explanation of the motions of the heavenly bodies. It was titled *Philosophiæ Naturalis Principia Mathematica*. Besides establishing Astronomy on scientific principles, he also made valuable additions to Optics and Mathematics. He died in the year 1727.

726. Another distinguished English astronomer, **Dr Edmund Halley**, was born in 1656 and died in 1742.

He suggested the transit of Venus over the sun's disc as a means of finding the sun's parallax; and calculated the elements and predicted the return of the comet which now bears his name. He made many valuable contributions to Astronomy, of which the preceding are the most notable.

727. DR BRADLEY, born in 1692, made the two capital discoveries of the aberration of light and nutation of the earth's axis; besides many other improvements in astronomical science.

728. CLAIRAUT, D'ALEMBERT, EULER, SIMPSON, LA PLACE, LA GRANGE, and LA LANDE made many improvements and extensions in astronomical science.

729. SIR WILLIAM HERSCHEL, towards the close of the last century, discovered URANUS and his satellites, the two inner satellites of Saturn, and ascertained its ring to be double. He also discovered the remarkable phenomena of the binary stars, and extended immensely our knowledge of the fixed stars.

730. The preceding are the leading names connected with the history and progress of astronomy, and the principal steps which it has made. For a full history of the progress of this interesting science, the reader is referred to VINCE's Astronomy, or the History of Astronomy in the Library of Useful Knowledge.

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